Journal
of
The Franklin Institute

AUGUST, 1951

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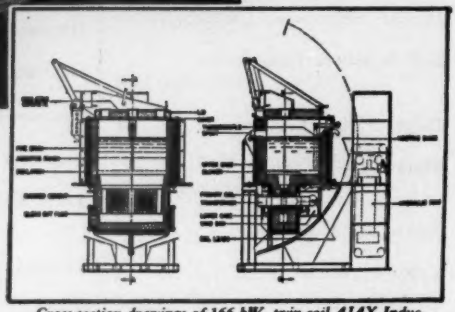

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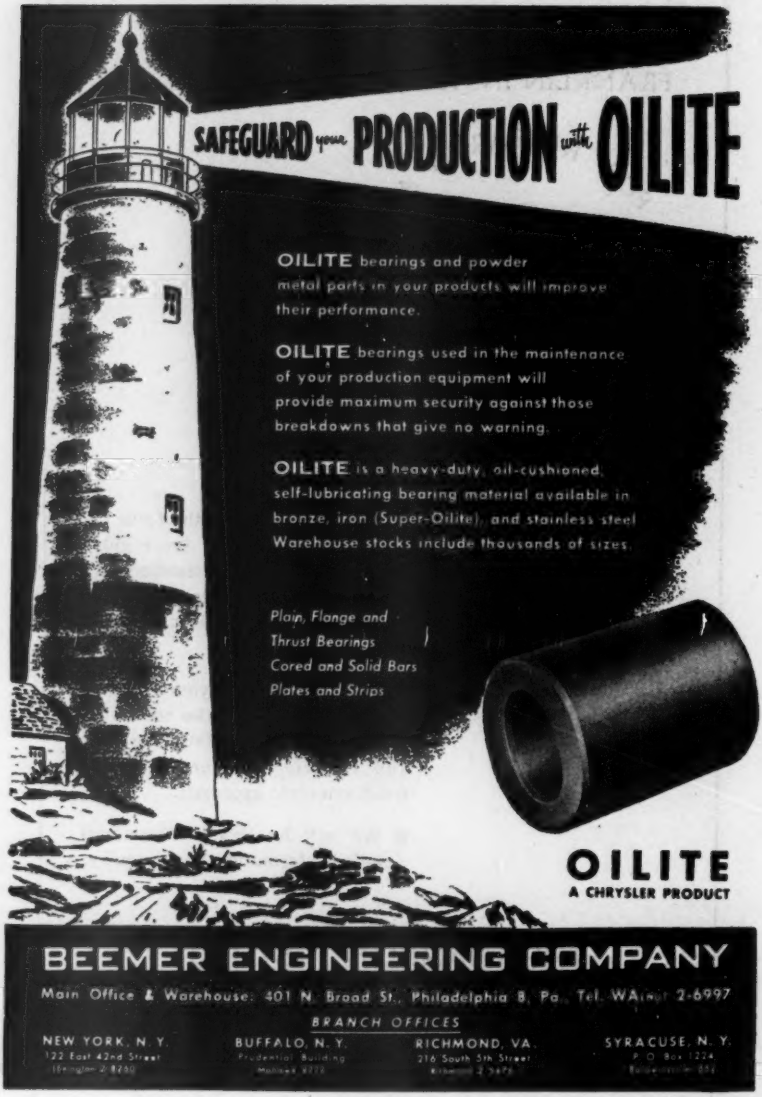
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Published at
Prince and Lemon Streets, Lancaster, Penna., by
THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA
Benjamin Franklin Parkway at Twentieth St., Philadelphia 3, Penna.

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Vol. 252 AUGUST, 1951 No. 2

THE VALVED-TREMIE APPLIED TO SUBAQUEOUS CONCRETE STRUCTURES

BY

A. BYRON HUNICKE[1]

ABSTRACT

This paper traces recent developments in types of tremie pipe used when depositing concrete in water and the method of operating them.

It relates specifically to research with valves to eliminate the hazards of the old open tremie pipe and describes one which literally makes an elongated pneumatic caisson of the tremie.

This was used extensively and with marked success for placing over 300,000 cu. yd. of concrete.

The paper also covers the routine of maneuvering such a tremie and is supplemented with numerous illustrative plates, photos and a table showing the sequence, size and location of monoliths poured by this method. It also gives the results of tested cylinders drilled out of the finished work.

The research was by the author and his staff assistants, and the work was executed under his personal direction.

INTRODUCTION

Among the problems posed by the construction of Dry Docks 4 and 5 at the Philadelphia Navy Yard was that of depositing large amounts of concrete in forms at the bottom of a pool of water from 50 to 60 ft. deep by means of a tremie.

Since the concrete was to compose the bottom and side walls of a battleship building and repair dock, performing all the functions of structural concrete, the need for a thoroughly dependable method for placing it was indicated.

The conventional tremie in use prior to 1940 had consisted of a simple steel pipe suspended in water (generally, though not always, in a nearly vertical position) so that its upper end would be above the surface and the lower end near the bottom of the forms to be filled.

[1] Industrial Engineer, Spring Hill, Ala.; formerly, Planning and Equipment Design Engineer, Drydock Associates, U. S. Navy Yard, Philadelphia, Pa.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

A funnel shaped hopper was usually attached to the upper end of the tremie to facilitate pouring concrete into it. Attachments are provided on the outside of the funnel or the tremie pipe itself for maneuvering it and for holding it in position, as well as for lengthening or shortening it.

When using the tremie, it seems to have been recognized that motion of the water caused cement particles to disengage themselves from the mix and float away, so means were devised to keep water from contact with the wet concrete mix until it emerged from the lower end of the tremie at the place of deposit. This often involved a good deal of both lateral and vertical movement of the tremie to get it

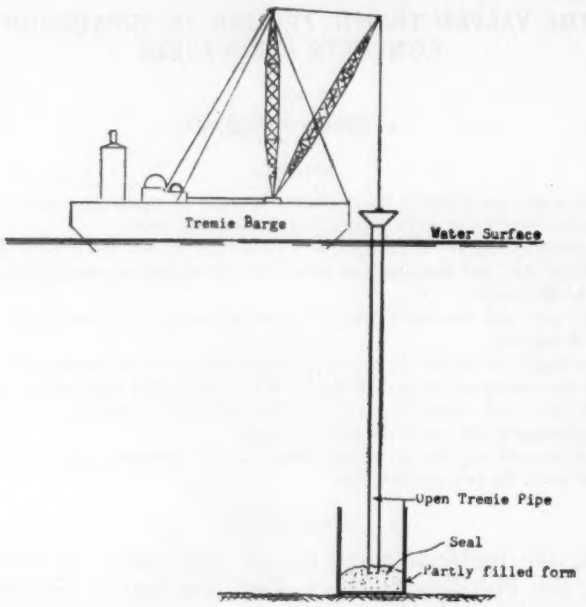


FIG. 1. Tremie pipe suspended in a submerged form.

into the corners of forms and around obstructions such as reinforcement and bracing members. It also developed the practice of placing a sort of sliding plug in the tremie pipe ahead of the concrete to keep it apart from the water in the pipe itself while the column of wet concrete descended. Plugs were of such various kinds as satisfied the notions of the men in charge, so sometimes a sack filled with cement, sand or mortar, or simply a bunch of straw, or a bundled up sack was used for a plug. The general notion was to get a batch of wet concrete down, out and around the lower end of the tremie pipe as expeditiously as possible, to seal off the water, and continue the concreting operation with the discharge end of the pipe kept buried in the wet concrete. When this

seal was "lost" (broken) water entered the tremie, ruining the mix by washing out cement and the operation was stopped. Then another plug was inserted in the tremie before attempting a new seal.

To lend scale to the operation, the author knows of work employing tremie pipes as small as 6 in. in diameter and as large as 17 in. in diameter depositing concrete in water as much as 80 ft. deep.

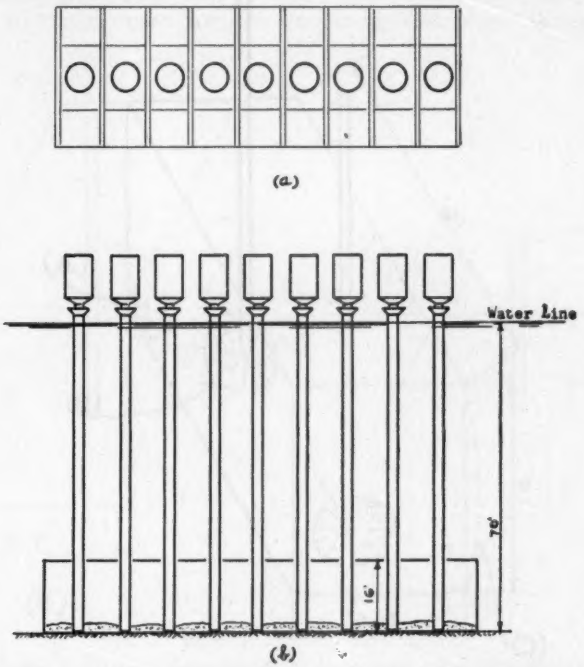


FIG. 2. Group of tremie pipes used on a dry dock in Hawaii.

(*a*) Plan. Pontoons supporting tremie pipes (not shown in (*b*)). Eight spaces at 10-ft. intervals. Hoists, etc., omitted for clarity.

(*b*) Section. 6-cu. yd. hoppers fed by 4-cu. yd. buckets, into tremie pipes of 17-in. inside diameter.

It is doubtful whether anyone can say when or where the first tremie was used. Mr. Eugene E. Halmos, Engineer of Design Review, Dry Dock Engineers, New York, said in 1943 that that method was over 35 years old (1).[2] Rear Admiral F. R. Harris, an authority on Naval Dock Construction mentions its use on the first Pearl Harbor dry dock 1909–13 (1). Mr. A. Tauber, Designing Engineer, F. R. Harris, Consulting Engineer, N. Y. refers to its use on the Detroit River Tunnel in 1906 (1). He also mentions an application of this method

[2] The boldface numbers in parentheses refer to the references appended to this paper.

of depositing concrete in Sweden in 1911. Efforts to obtain authentic records of earlier uses were fruitless.

Figure 1 illustrates a tremie pipe as described above suspended in a submerged form.

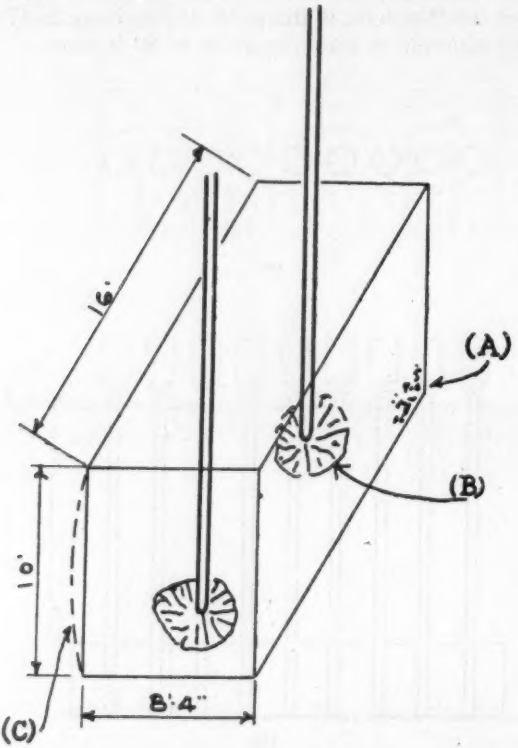


FIG. 3. Test block of concrete poured using two tremie pipes 10 ft. apart and 4 in. above bottom. Rate of pour was 4 cu. yd. in 13.5 minutes. Concrete was composed of seven sacks of cement and aggregates containing 42 per cent fines. Slump was 5 to 7 in. Tremie pipes were 17 in. in inside diameter. Bulges in form and scoured bottom were due to jetting action of water forced from pipes by descending charge of concrete. The scour occurred again when the test was repeated. Concrete rose 7 ft. per hour in the form.

(*A*) Scoured material lodged under side walers of form.
(*B*) Bottom scoured 5 ft. in diameter and 18 and 24 in. deep.
(*C*) Side of form bulged 6 in.

FAULTS IN PREVIOUSLY USED METHODS OF DEPOSITING SUBAQUEOUS CONCRETE

In the first place, the use of a plug of any kind is objectionable. It introduces a foreign element into the concrete. Sacks, bundles of straw, etc., even bags of cement interfere with the homogeneity of the mass and its structural qualities. Their use is deplored and should be avoided.

The loss of a seal generally results in a structural flaw in the concrete. If the elapsed time before re-establishing a seal is enough for initial setting of the concrete already placed, it is almost certain that a cleavage plane will exist under the new seal.

A much more serious matter is the water in the tremie pipe below the plug when the initial batch of concrete is poured into it. Water being practically incompressible, that within the tremie pipe must be displaced to make room for the oncoming concrete. When a plug

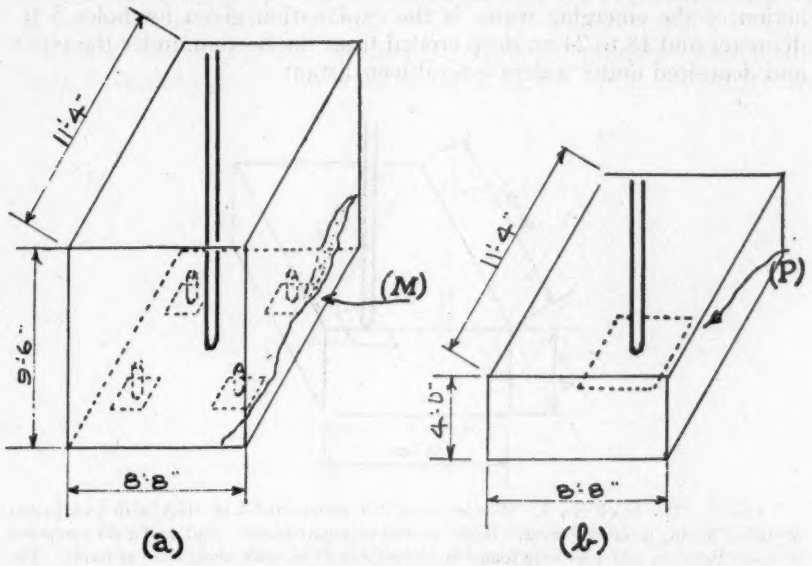


FIG. 4. Effect of dispelling water rapidly.

(*a*) Test block No. 3. Bottom covered with 20 gauge sheet metal with 20-in. square holes 5 ft. centers around dummy piles. 17-in. tremie used initial charge 4 cu. yd. of concrete weighing 15,984 lb. Water dispelled by a sack plug. Tremie 6 in. off the bottom.
M—Large pockets of loose material in corners and along sides of form.

(*b*) Test block No. 4. 17-in. tremie used with a sack plug ahead of the initial charge. Large pockets of silt and washed aggregates in corners and along sides of form as found in test block No. 3. 4 in. of scour occurred around the plate.
P—Plate 4 ft. by 4 ft. by ½ in.

was used the weight of the concrete above it acted like the piston of an hydraulic ram to force the water content of the tremie pipe down and out at its lower extremity.

A certain minimum head of concrete had to be built up to overcome friction in the pipe and start motion, but beyond that, concrete had to be added rapidly to maintain a net downward force in excess of the hydraulic back pressure. The complete lack of control and the desire quickly to deposit enough concrete to assure a seal conspire to urge haste

upon the operators. The result is rapid ejection of the water from the tremie pipe. This creates turbulence and eddy currents in and over the form and sometimes erodes the bottom directly below the tremie pipe casting eroded particles up into corners and recesses in the form structure (see experience at Pearl Harbor).

Figure 2 illustrates a group of 17-in. inside diameter tremie pipes used on a dry dock in Hawaii.

Figure 3 illustrates a test block poured as described above. Note that although the tremie was raised 4 in. from the bottom, the jetting action of the emerging water is the explanation given for holes 5 ft. diameter and 18 to 24 in. deep eroded from the bottom under the pipes and deposited under walers several feet distant.

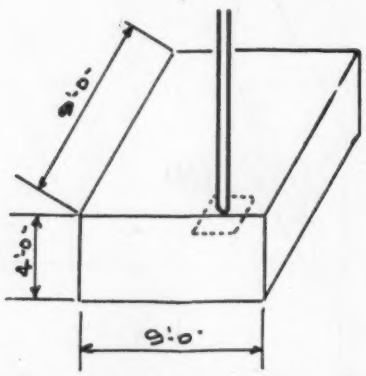


FIG. 5. Test block No. 5. Wooden plate 2 ft. square and 4 in. thick with ½-in. gasket of rubber belting placed by diver. Badly washed segregated stone, sand, and a silt composed of washed cement and fines were found in corners and 12 in. wide along sides of forms. The lower 2 ft. of the corrugations of the form sides were filled with loose material. A 17-in. inside diameter tremie pipe was set over the gasket, pumped out and charged with 4 cu. yd. of concrete, then raised 9½ in. About 2 cu. yd. ran out very quickly, leaving 32 ft. of concrete head in the tremie.

The effect of dispelling the water rapidly as from a ram jet is seen again in Fig. 4 (Test Block No. 4) where 4 in. of scour around the 4 ft. square plate on the bottom of the formed area was thrown into the corners and along the sides of the form. Also, the turbulence and currents set up washed cement from the aggregates. See also Fig. 4 (Test Block No. 3) and note that a sack plug was used. The bad effects of scour and turbulence upon the form, the bottom and the concrete can be seen in later figures also. In each case the rapid expulsion of the water from the tremie pipe was largely responsible. It could only upset the tranquil static condition of the water in, over and under the form, rendering it too agitated for safe concreting operations.

Such agitation of the water in such relatively small confined areas as for test blocks ranging up to 10 by 16 ft. in plan and from 4 to 16 ft. in height, is apt to die out slowly. If, by raising the tremie pipe or otherwise permitting the concrete to flow out, it comes in contact with water in such a state of unrest, segregation of the cement is sure to occur if 16,000 lb. of concrete are fed into the throat of a tremie pipe 70 ft. long already so full of water as to balance the hydrostatic head in a form. The falling concrete will produce a force equal to 1,120,000 ft. lb. distributed over the fraction of time required to push the column of water out ahead of it.

Since water may be considered a non-compressible liquid this force is transferred to the mass of water in the form. It overcomes

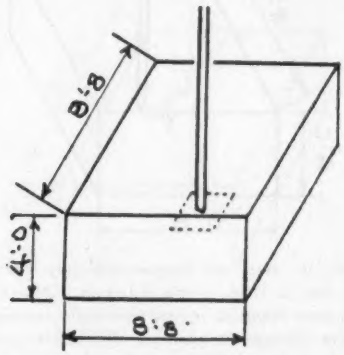


FIG. 6. Test block No. 7. Wooden plate and gasket as used with test block No. 5. 20-gauge metal bottom, no openings. Washed and segregated material found in lower corners and lower 2 ft. along the sides of the form. Initial charge 7.5 cu. yd. (29,970 lb.). 17-in. inside diameter tremie pipe pumped out and filled with 4 cu. yd. of concrete and a reserve so that 7.5 cu. yd. were released when the tremie was raised off of the gasket.

the inertia of the water content of the form setting it in turbulent motion and that portion which the water is unable to dispel quickly expends itself eroding the bottom or injuring the form or both.

Test block No. 5 is interesting because it was the first of the Pearl Harbor tests in which water was removed from the tremie pipe before charging it with concrete, but no air cushion as used by the author at Philadelphia was provided, and the tremie was raised so high (9½ in.) that the concrete rushed out with the full force of the head differential between the weights of concrete (148 lb. per cu. ft.) and salt water (64 lb. per cu. ft.) which created the turbulence with resulting scour and segregation. Note that the flow came to rest while 32 ft. of concrete remained in the tremie (148 lb. × 32 ft. = 64 lb. × 70 ft.,

nearly) which balances since they were pouring in 70 ft. of water. (See Fig. 5, Test Block No. 5*; and Fig. 6, Test Block No. 7.**)

Note that a change in the diameter of tremie pipe did not relieve the condition. (Fig. 7, Test Blocks No. 9–12).***

Jerking the tremie pipe up and down must have prolonged the agitation of the water or given it new impetus, perhaps setting up new or cross currents in the form originating right around and along the pipe itself in the immediate vicinity of the freshly deposited concrete.

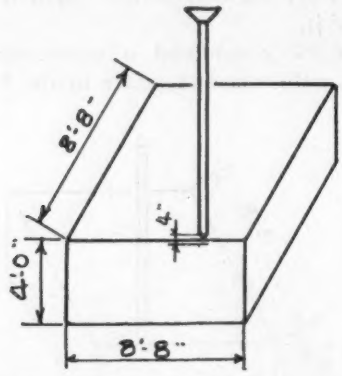


FIG. 7. Test block No. 9. 6-cu. yd. hopper with gate was mounted above the funnel top on the tremie, which had a 12-in. inside diameter. 20-gauge metal bottom with no openings. Lower foot was loose material, second foot slight cohesion, much washing. Initial charge: plug sack of excelsior followed by 4 cu. yd. of concrete poured continuously. Tremie was jerked up and down 3 ft. during the flow.

While this jerking may have helped produce or maintain flow by breaking the frictional adherence of the concrete to the inside of the walls of the pipe or a tendency to arch, it must endanger the seal and cause motion in the water thus aggravating the tendency to disturb the concrete mix, washing out cement, segregating the aggregates and

* Test block No. 6 was like No. 5 except that the bottom was covered with corrugated sheets similar to those used on the side walls of the forms. It was even poorer than No. 5.

** Test block No. 8 was like No. 7 but an initial charge of 8 cu. yd. was prepared and fed through the tremie continuously. Washed and segregated material was found in the lower corners and 18 in. high along the sides of the form.

*** Test block No. 10 same as No. 9, but a 15-in. inside diameter tremie was used. Pipe was jerked as much as 3 ft. Block fell apart when form was removed.

Test block No. 11 same as No. 9, but a slightly dryer concrete was used in a 15-in. inside diameter tremie set 6 in. above the bottom, raised to 2 ft. and jerked so that at one time the end of the tremie was 1 ft. above the deposited concrete.

Test block No. 12 same as No. 9, but a slightly leaner and a more liquid concrete was used in a 17-in. inside diameter tremie pipe set 10 in. above the bottom and lowered 5 in. while sealing. Initial charge: a burlap bag plug followed by 4 cu. yd. of concrete. Tremie was jerked to 2 ft. 6 in. above the bottom and set 2 ft. off center in the form. The block contained a core of concrete about 5 ft. in diameter. Balance washed material.

introducing substantial quantities of additional water intrusions into the concrete already deposited (See Fig. 7, test block No. 9***). Changing the slump of the concrete from 6 to 7 in. thus increasing the plasticity reduced the need for jerking the pipe so showed a little but not enough improvement. It at least added no turbulence to the water and reduced friction between concrete and pipe. (See Fig. 8, Test Block No. 13.)

Referring to Test Block No. 14,† it is interesting to note that a substantial increase in the fine aggregate helps the flow of concrete down the pipe even though it had only a 5½-in. slump compared with 6 to 7 in. used for earlier experiments. This point will be taken up later in this paper when dealing with other phases of the subject.

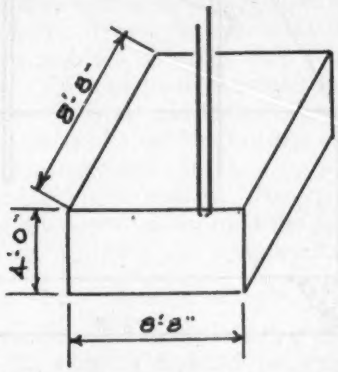


FIG. 8. Test block No. 13. Concrete same mix but slightly dryer than used in test block No. 9. 17-in. inside diameter tremie set 9½ in. above bottom and lowered as soon as flow started. Badly washed sand and stone in lower 18 in. of sides and corners of form. Some honeycomb and sand streaks in the mass.

Jerking was resumed and turbulence gave trouble as before.

Figure 9, illustrating Test Block No. 15, is interesting because of the variety of conditions it attempted to meet. However, the plug was used, and the hydraulic ram effect with its aftermath of turbulence followed automatically. This is attested to by the observation "3 feet diameter of good concrete under pipe location surrounded by loose rock stirred up from the bottom by the initial charge. Loose rock 2 feet deep in block." Of course they had buried the pipe one foot in the rock before charging it which the author believes added to the amount of loose rock moved, but when there was a head of 35 ft. of

† Test block No. 14. Initial charge has 8.6 sacks of cement and 500 lb. per cu. yd. excess sand but was poured relatively dry (5½-in. slump) into a 17-in. inside diameter tremie set 6 in. above the bottom. The tremie was jerked once, being lifted 3 ft. above the bottom which then put its lip 6 in. above the concrete in the form. The bottom was scoured 12 in. deep by 3 ft. diameter under the tremie, puncturing the 20-gauge metal covering. Lower foot in the form was washed loose material, mostly sand, but the balance was badly segregated, honeycombed with large streaks of sand throughout.

concrete it was exerting a net unbalanced downward pressure of $\frac{150 \text{ lb.} - 64 \text{ lb.} \times 35}{144} = 21$ psi. less approximately 2 psi. for friction. Its velocity upon striking the bottom was 47.27 ft. per second (laws of gravity), so the force exerted upon the loose rock tending to displace it must have been considerable.

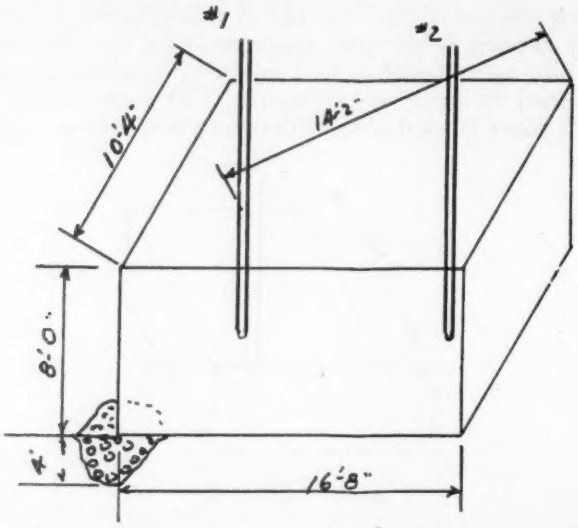


FIG. 9. Test block No. 15. 17-in. inside diameter tremie pipes set 5 ft. 2 in. from the ends of the form and 3 ft. 4 in. from each side. 3 ft. diameter good concrete under No. 1 tremie surrounded by loose rock stirred up from the bottom by initial charge. A stratum of washed materials of low cohesion forced from pipe 1 into concrete surrounding pipe 2 about 2 ft. from bottom of form. No. 1 tremie was buried 1 ft. in rock and No. 2 was 1.1 ft. in the bottom when charged. Hole dug and filled with 2- and 3-in. rock in advance. Tremie No. 1, initial charge was burlap sack followed by 4 cu. yd. of concrete driving out the water in the pipe. Tremie No. 2, initial charge was 8 cu. yd. of concrete filling it and its hopper. This pipe was gradually raised until flow started, then lowered to its original position. Well packed coral back fill bottom.

The faults in such methods of depositing tremie concrete may be summarized as follows:

1. "Plugs" of various sorts are objectionable in the concrete. They should not be permitted. (The U. S. Navy more recently has banned their use.)

2. The ejection of the water content in the tremie pipe by utilizing the force of a falling column of concrete causes eddy currents, outflow currents and turbulence in the form so violent as to bring up substantial amounts of material scoured from the bottom depositing it in corners and recesses of the form.

3. The water ejected from the tremie pipe displaces water in the form setting up an out-flow current with such eddies as result from the shape of the form and the position of the tremie in it.

4. Turbulence does not die out quickly. It often washes substantial quantities of cement out of the concrete and also causes segregation of the aggregates.

5. Violent or even considerable movement of the tremie pipe to force a flow agitates the water endangering the seal and the quality of the concrete.

6. Loss of a seal, frequent under this method, is often accompanied by a violent inrush of water into the tremie pipe, thus again setting up currents to disturb the surface of the freshly deposited concrete, washing out cement and fines and setting up a honeycomb condition of minute cavities filled with water. When the oncoming charge for a new seal fails to displace these globules of water they remain imprisoned and their grouping makes a shear plane of weakness in the structure.

7. Turbulent water carrying quantities of cement and sand from the concrete or loose material from the bottom is often so turbid that divers cannot work to advantage in it.

8. The whole operation lacks control. No one can be sure that the concrete so poured really possesses the qualities intended except to the extent revealed later by sampling the completed structure.

CONTEMPORARY METHODS

The United States Navy dry dock building program begun shortly before World War II, with its demand for enormous quantities of tremie-placed concrete, was a challenge to scientists and engineers to produce methods and equipment such as would eliminate at least the more dangerous and frequent hazards involved and assure monoliths of structural grade concrete when deposited in water of substantial depths and in forms so large as to embrace well over 1000 cubic yards in one continuous pour.

Facing this problem were a number of engineers of broad experience, unknown to one another, each pledged to secrecy compatible with the need for national security, and each approaching it in his own way as influenced by his individual background, environment, and associations.

The known results of their work express eloquently how keenly they sensed the need for better methods and for initiative and ingenuity.

A forerunner of this work was Mr. Arthur R. Anderson (2), Asst. Civil Engineering Department, M.I.T., whose "Study of Sub-aqueous Concrete" reported in Feb. 1937 covered small scale experiments depositing a series of concretes to compare the bottom dump bucket method with the tremie method. He reported tremie concrete averaging 17 per cent stronger than that placed with a dropbottom bucket, among other conclusions. His tremie, however, was plugged and completely filled with concrete before immersion.

Mr. T. E. Stanton (3), Materials and Research Engineer, Division of Highways, State of California, also reported in June 1937 on subaqueous concrete used on San Francisco-Oakland Bay Bridge. He and Mr. Stanley M. Hands found little difficulty in securing good quality concretes when using either the bucket or the tremie, but they were concerned with a plasticity that would help blend successive batches and fill out the corners in the form.

But the real effort to improve on the methods of tremie concrete came in 1939–40 when the Naval Dock building program called for

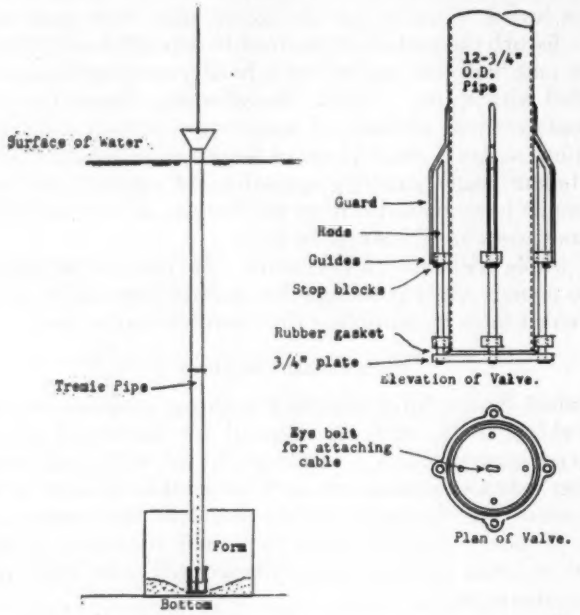


FIG. 10. Schematic drawing of plate foot valve.

hundreds of thousands of cubic yards of high quality structural concrete to be deposited under water. Capt. P. J. Halloran (C.E.C.) U.S.N., and Mr. K. H. Talbot (4) working at Norfolk, Va., Capt. W. Mack Angas (C.E.C.) U. S. N., Lt. Comdr. E. M. Shanley (5) (C.E.C.) U.S.N.R., Lt. J. A. Erickson (C.E.C.) U.S.N., the author and Mr. James Agnew at Philadelphia, and others were all busy with this problem at once and it remained on our hands through 1942 and 1943. Others deeply interested if not in constant hourly contact with it were Admiral F. R. Harris, Messrs. E. E. Halmos, A. Tanker, G. T. Gilman and Admiral W. H. Smith.

Messrs. Halloran and Talbot, concerned with the hydraulic ram effect of the old type of "plugged" tremie sought to avoid disturbing the rock bed or concrete already deposited below the tremie pipe by attaching a plate foot valve (Fig. 10) to deflect the emerging concrete sidewise and upward. A cable drawn up through the tremie was rigged and used to close the valve tightly enough to permit unwatering the tremie, thus eliminating the plug (4).

The method as they describe it (4) was as follows: the tremie was lowered into position, the foot valve was closed and a steam lift was used to eject the water imprisoned in the pipe. Then the tremie pipe was filled with concrete and the valve opened by lifting the loaded

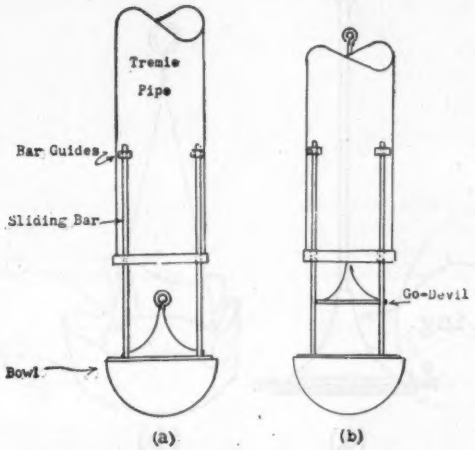


FIG. 11. Two alternative types of foot valves.
(*a*) Bowl type tremie foot valve.
(*b*) Foot valve with Kelley "Go-Devil."

tremie a maximum of 10 or 11 inches. The concrete ran out of the opening between the gate and the periphery of the bottom of the tremie pipe. Halloran and Talbot thought a 10-in. diameter tremie might have been better than a 12-in. but that is a matter relating somewhat more closely to the volume to be deposited per hour than to the method of placing the concrete.

With the type valve they used, there could be no gouging of the bottom directly beneath the tremie pipe, but since the bottom was very rough, being of broken stone so that there would be a high coefficient of friction over the area covered by horizontally moving concrete, one would expect some dislodgment of stone particles and their transport into corners of the form or to points along the boundary of the first batch, or seal, to emerge from the tremie pipe. The greater the initial

valve opening with its consequent out-rush of concrete, the more aggravated such bottom disturbances are likely to have been. Their theory for the foot valve operation, that is placement of the concrete by intrusion through the mass, can be right only at certain stages.

Assuming that a tremie pipe is in position, with its foot valve closed and is filled with "dry" concrete ("dry" meaning concrete poured into a pumped dry pipe) and that the valve is then opened releasing it to flow into the form against a head of water, the shape assumed by the surface of the emerged charge of concrete is extremely difficult to forecast. It may be influenced by the size of the charge, the shape and

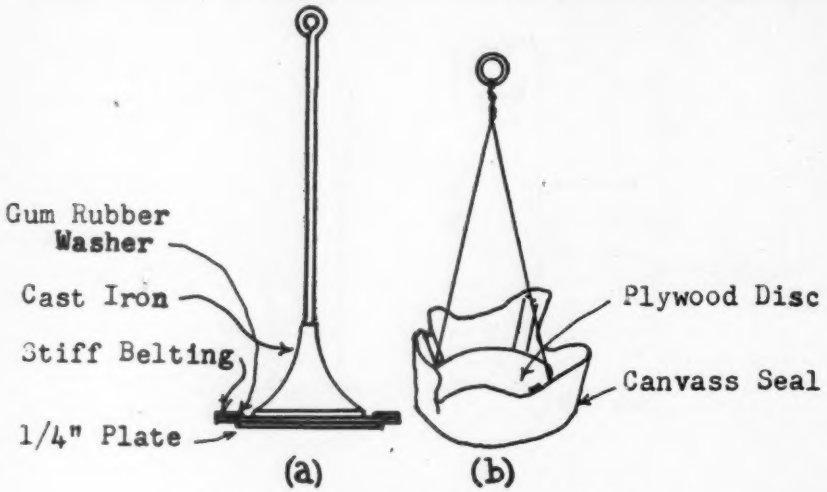
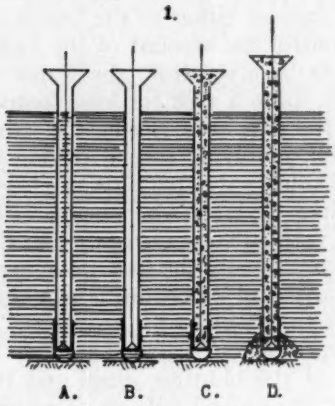


FIG. 12. Two "improved plugs" for use in tremie pipe.
(*a*) Kelley "Go-Devil."
(*b*) Bayonne "Go-Devil."

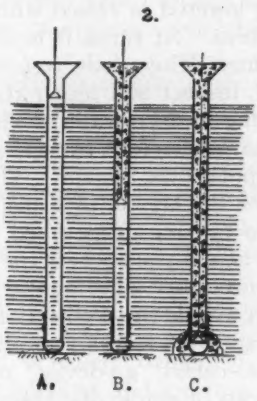
the size of the form, the slump of the concrete mass at the point of emergence, the size and shape of the aperture, the unit weights of both concrete and water; and the ratio of their heads on the orifice, and the position of reinforcement and bracing members, etc., in the form.

After enough concrete has emerged to establish a seal, that is to bury the valve opening within its mass, the shape of the surface may still be affected by a number of conditions, but with continuous flow of fresh concrete into soft unset pre-deposited concrete some intrusion seems likely in combination with a pushing of a portion of the pre-deposited concrete farther from the tremie toward the sides and ends of the form. The Halloran-Talbot experiments indicate this pushing effect with a concurrent tendency to even make the pre-deposited charge rise up along the side walls of the form.

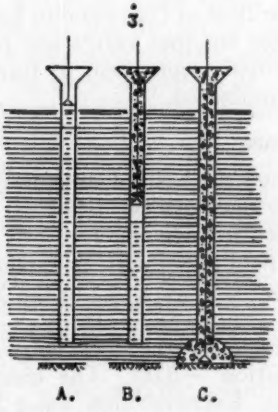
Indeed the author, though using the totally different principle and type of valve about to be discussed, observed this same trend and photographed it in sections cut from a block reclaimed during researches.



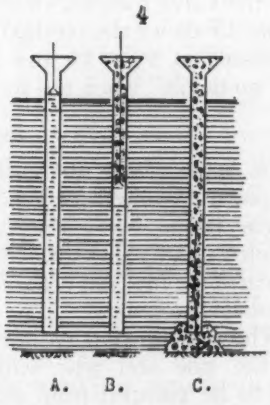
(A) Pipe in position with valve closed.
(B) Pipe pumped out.
(C) Pipe being filled with concrete.
(D) Pipe raised to discharge concrete.



(A) Placing Kelley go-devil.
(B) Weight of concrete on go-devil expelling water and air.
(C) Pipe discharging concrete.



Same as (2) above, but without valve.



Same as (3), but using Bayonne go-devil which is lost in the discharged concrete.

FIG. 13. Method of manipulating the foot valves and plugs illustrated in Figs. 11 and 12.

The pressures of the water against the concrete are in part responsible for this action. Indeed, each oncoming batch pushes some of the previously deposited material outward and upward as will be described in more detail later.

The foot valve offers a substantial advance in the art over the old "plug" method of charging a tremie pipe but it also has several objectionable features. The valve guides and other external parts (Fig. 10) are apt to catch on reinforcement, form bracing, etc., either while being lowered or raised with danger of damage either to the tremie or the form. At times it is difficult to control the amount of the valve opening. The whole tremie pipe has to be lifted from the water to clean, inspect and repair the foot valve, quite a task for long tremies working in deep water. The water in the pipe after closing the valve has to be ejected—an operation in itself, involving special rigging to manipulate the ejector. The plate and other valve parts on the lower end of the tremie pipe displace deposited concrete when being withdrawn causing a disturbed area and a vertical cone of rupture in the mass at the place where the pipe was set. Finally the foot valve itself is unnecessary since another type of valve and procedure is available which avoids these objections, the valve-tremie pipe.

Figure 11 shows two alternative types of foot valves and Fig. 12 two so-called "go-devils" used in lieu of the old-time plugs and the methods of employing them. The first one proved difficult of manipulation. Often the gate would not completely close so the pipe could not be entirely freed of water. The addition of the "go-devil" shown in the second sketch helped maintain a "dry" concrete but reverted to some of the old hydraulic ram effect of unwatering and some claimed that the valve rods interfered with the free flow of the concrete badly. Figure 13 shows the method of manipulating the foot valves and plugs illustrated in Figs. 11 and 12. It was found impractical to retrieve the "go-devils" when the foot valve was eliminated.

THE VALVE-TREMIE PIPE

In August 1940, the author was assigned the task of designing the equipment required for concreting the dry docks to be constructed at League Island Navy Yard. Responsibility for the concrete mix was included as was also the scheduling of all field operations, ballasting of the caisson gates and a number of other features accessory to the Yard expansion program.

The specification required tremie concrete for the dock floors and for the side and rear walls below elevation −6.00. The concrete was to be pumped from mixer to tremie. Extreme high water level was at elevation +10.00 ft. above Delaware River datum. The top of the prepared stone bed which composed the bottom of the floor form for the first dock was at elevation −50.30 ft., thus one had to be prepared to deposit concrete in 60.3 ft. depth of water.

Floor forms were designed to hold from 1000 to 1259 cu. yd. and the inter-form spaces a little less. Wall forms were designed to hold an average of 850 cu. yd. The design of the forms and reinforcement

had preceded this assignment. Their safe strength was limited by an assumed maximum rate of filling of 4 ft. per hour. The reinforcement was composed of groups of large bars placed where best suited for structural economy.

The form bracing and the position of reinforcement imposed severe limitations on the size, number and spacing of openings available for tremie pipes.

The specification also demanded a concrete developing a minimum of 3500 psi. ultimate compressive strength at age 28 days.

With these factors the author started work. While various suggested plant layouts were under consideration the results of test blocks poured by the old "plug" method at Pearl Harbor began to arrive. They were so disturbing that an observer was sent there to bring back the entire record for study. Much of this record is reproduced in Figs. 3 to 9 inclusive. The need to prevent hydraulic ram effect from scouring the bottom and turbulence such as would segregate the particles in the mix and wash cement away was seen immediately.

The author had witnessed the placing of many cubic yards of concrete below water, but most of it was in caissons under compressed air where the water could be driven away or controlled during the depositing. At such times, however, as water was present, there had been little or no trouble with the quality of concrete so long as the water remained tranquil and the placing gently done, but when there were currents, when quick handling caused waves, when turbulent waters touched the plastic concrete there was always a loss of cement and segregation of the aggregates. The Pearl Harbor test blocks bore out these observations.

When working with caissons under compressed air, the air balances the hydraulic head keeping the water from entering so the working chamber can be kept dry and so concrete can be deposited in it. What more logical reasoning could there be than the idea of converting the submerged portion of a tremie pipe into a small diameter elongated caisson under air? Now, a caisson consists of a working chamber beneath a lock or valve through which materials may be brought in. So, if an appropriate design of air lock or valve were inserted in the tremie pipe not at its foot, but at some higher level, and a compressed air pipe were tapped into its wall below this valve, conditions such as apply to the working chamber of a caisson would be simulated (see Fig. 14).

A caisson has no floor. It is in effect a diving bell, yet the pressure forcing back the water keeps it dry. So also the simulated condition would keep the tremie dry though there be no closure at its lower extremity. Concrete in its "working chamber" below the valve would be safe against "contamination" from the water in which the tremie was immersed. Thus if a tremie pipe so arranged stood on the bottom of

the form, be that surface ever so rough and the points of contact few, water would not enter from outside. If then, the compressed air in the tremie pipe could be replaced with concrete to a depth such as to precisely balance the head of water outside, a static condition would exist in which no motion would occur. That is to say, concrete would not leave the foot of the pipe nor water enter. At any points of direct contact such as might be due to unevenness of the bottom, there would be a clear line of demarkation between the water and the plastic concrete

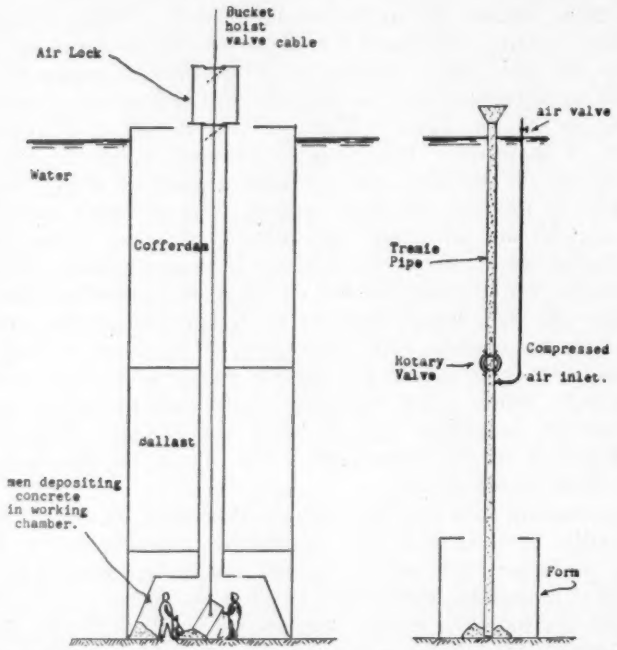


FIG. 14. Analogy between depositing concrete in a caisson under compressed air and through a tremie pipe equipped with a rotary valve and compressed air inlet, the author's method.

as though each were not liquid but two solids placed side by side. Experience in caisson work tends to this line of reasoning because water bearing soils exposed while sinking caissons in compressed air do not "leak" when the pressure is kept up.

One may reason further. Water is a non-compressible liquid. That within a tremie pipe must be pumped out as reported by Capt. Halloran and Mr. Talbot or pushed out as by a "go-devil" plug to make way for a charge of concrete. When pushed out it can only displace water in the form causing eddies, currents, turbulence, and grief and uncertainty to those using the tremie. Compressed air,

on the other hand, obeys the laws of compressible gases. When a relatively small stream of it is applied to the working chamber of a caisson or diving bell it forces the water out ahead of it gently and slowly. The movements set up are slow, and tranquility is quickly restored. More than that, when the caisson is filled with air any excess supplied escapes around the lower rim and rises to the surface in small bubbles. Observing these one may turn off the air supply thus exercising a certain control with precise knowledge as to when the cause of currents in the water ceased.

Applied to an air-locked or valved tremie (Fig. 14) the volume of pipe below the valve being relatively small, only a little compressed air is required to force out the water. It can be admitted slowly so the water level will descend quietly, and it can be turned off as soon

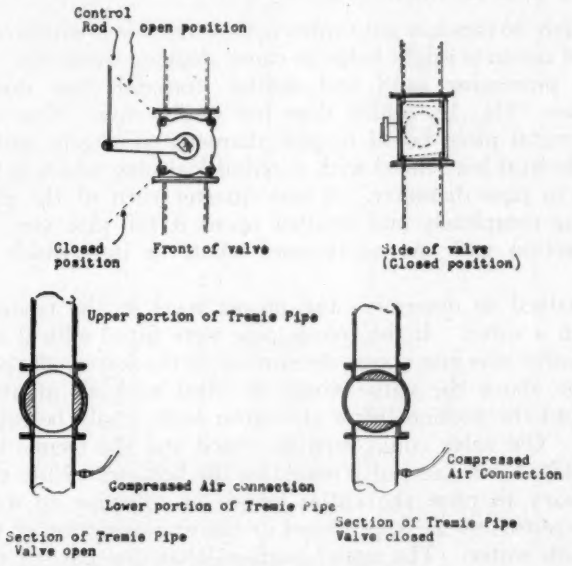


FIG. 15. Rotary valve.

as the first bubbles are seen rising. In a very few minutes thereafter the water in the form should be still and ready to receive the concrete.

The conclusions thus reached in theory backed by experience in compressed air work were that:

1. A tremie pipe air locked or valved off at some point above its lower end would really be compartmented so that the slow application of compressed air to its lower chamber would un-water it, causing only very slight and brief disturbances in the water outside providing the pressure of the air supplied was equal to the hydrostatic head.

2. When a pipe thus unwatered standing on the bottom is filled with plastic concrete, said concrete will be of the same consistency as before entering the tremie—that is, there will be no washing effect upon the cement nor segregation of aggregates. Concrete of the right proportions as mixed will have reached the bottom of the form unaltered but will not yet have been released from the tremie.

3. Turbulence will have been reduced to harmless proportions or ceased entirely before the concrete is released into the formed space.

4. Where direct contact between concrete and water does occur, it may be likened to that of solids as contrasted with the mutual mingling of liquids.

5. The practicability of this theory depended on a suitable lock or valve, one that would be air and water tight when closed, yet could pass plastic concrete when open.

Obviously no check or gate valve with recesses into which constituent particles of concrete might lodge to cause clogging would do. Happily, industries processing pulp and similar materials had developed a rotary valve (Fig. 15) which does not easily clog. Note that it is simply a metal piece bored to pipe diameter vertically with a much larger horizontal bore fitted with a cylindrical plug which is also bored vertically to pipe diameter. A one quarter turn of the plug closes the opening completely and another opens it full pipe size. It turns either direction and has no recesses whatever into which materials can lodge.

It remained to determine the proper level in the tremie pipe to install such a valve. If the tremie pipe were fitted with it and raised until the valve was just above the surface of the water, all that portion of the pipe above the valve would be filled with air at atmospheric pressure and the portion below the water level would be full of water (Fig. 16). The valve could then be closed and the tremie lowered in place until its lower extremity rested on the bottom. Note that it was not necessary to raise the entire length of the pipe to water level. The valve must now be kept closed or the upper portion of the tremie will fill with water. The upper portion, that dry part of the tremie above the closed valve may now be filled with concrete after which compressed air supplied to the portion below the valve will render it also dry by unwatering it (Fig. 17).

Upon turning off the air when the first bubbles show, we have a dry tremie pipe divided into an upper and lower portion by a valve. The upper portion is full of plastic concrete while the lower is full of air at a pressure just equal to the hydrostatic pressure of the water outside. To maintain equilibrium the valve can only be opened when the weight of concrete above it balances the pressure of the air beneath. Expressing it another way, the weight of concrete above the valve must equal the hydrostatic head of the water plus a little to overcome friction against the walls of the upper part of the tremie and start the flow.

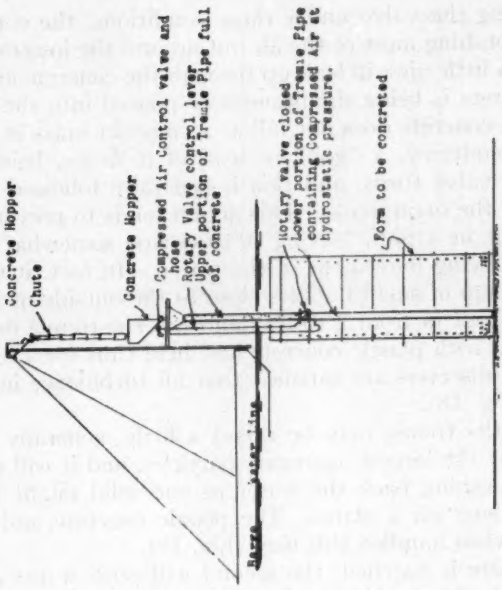

Concrete Hopper
Chute
Concrete Hopper
Compressed Air Control valve and hose
Rotary Valve control lever
Upper portion of Tremie Pipe full of concrete
Rotary valve closed
Lower portion of Tremie Pipe containing Compressed Air at hydrostatic pressure.
Form to be concreted
Water Line
Barge

FIG. 17. Valved-tremie pipe preparatory to depositing concrete in submerged form. Second step.

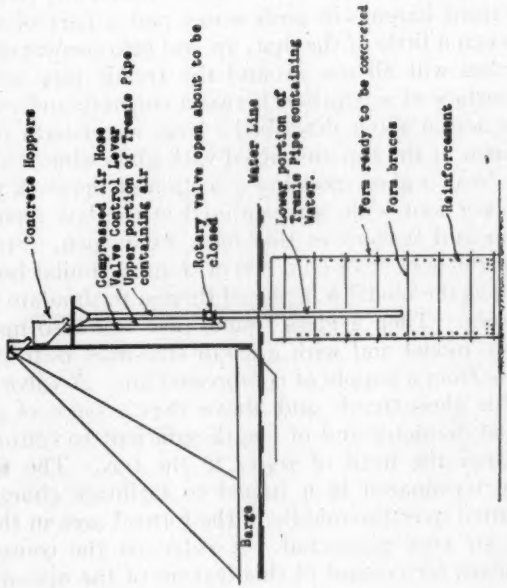


FIG. 16. Valved-tremie pipe preparatory to depositing concrete in submerged form. First step.

Upon opening the valve under these conditions, the concrete falls to the bottom pushing most of the air out around the lower edge of the tremie pipe. A little air will leak up through the concrete even though additional concrete is being simultaneously poured into the top of the tremie, and the concrete does not fall as a compact mass in the tremie pipe. On the contrary, a "gob" or wad of it drops, being the first through as the valve turns, and this is generally followed by several others ahead of the main mass. This action tends to prevent air from being forced out in a puff, leaving it to escape somewhat gradually, thus further reducing movement in the water. In fact, it rises to the surface in a stream of small bubbles close to the outside of the tremie, and dissipates itself in from 2 to 3 minutes. The tremie may then be completely filled with plastic concrete and held thus for a few minutes if desired until observers are satisfied that all turbulence in the water has subsided (Fig. 18).

After that, the tremie may be raised a little, generally enough to pass comfortably the largest aggregate particles, and it will flow slowly into the form pushing back the water as one solid might be used to push another about on a plane. The plastic concrete and the water do not mingle when handled this way (Fig. 19).

If the concrete is batched, the second will push water and a part of the first batch ahead of it, particularly portions close to the tremie, thus flattening out the dome or seal created around the tremie by the first batch. A third batch will push water and a part of the second and sometimes even a little of the first, up and into corners of the form. Succeeding batches will fill out around the tremie pipe and tend to flatten out the surface of separation between concrete and water.

To study the action above described a large water-tight rectangular box was built, open at the top and fitted with glass windows in each of the four sides. Next a glass model of a section of the dock floor form, made to a 2 in. per foot scale was centered in the box resting on the bottom. The top and bottom of this form were open. Since it was proposed to pour the dock floor on a bed of stone, a similar bed screened to the same scale as the model was placed therein to simulate the roughness of the bottom. Then a glass tremie pipe was also made to the same scale as the model and with a small side inlet near the top for connecting a hose from a supply of compressed air. A valve was fitted to the top of this glass tremie and above that a piece of galvanized iron pipe of equal diameter and of length sufficient to contain enough concrete to balance the head of water in the box. The top of this tremie assembly terminated in a funnel to facilitate charging. The tremie was mounted over the middle of the formed area in the box and the compressed air hose connected. A valve on the compressed air line provided means for control of this feature of the operation. The mounting was arranged to alter the elevation of the tremie pipe when desired and to move it laterally.

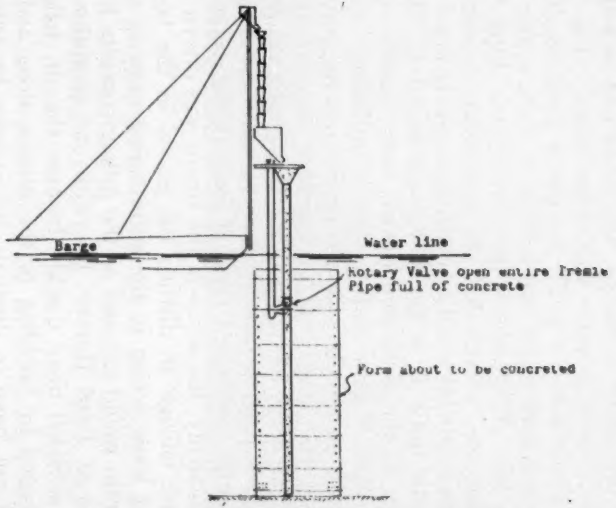


FIG. 18. Valved-tremie pipe just before depositing concrete in submerged form. Third step.

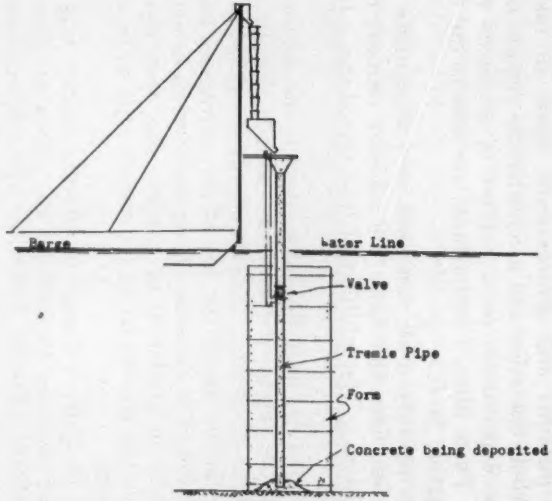


FIG. 19. Valved-tremie pipe at the beginning of concreting a submerged form.

Lights were installed and arrangements made to take moving pictures of the whole operation and a considerable amount of film was devoted to these experiments on a number of occasions when they were repeated. These films, I understand, are now in the files of the Navy at Washington, D. C.

In some contemporary work, sand was used to simulate the action of the concrete but since this lacks the cohesive element it leads to erroneous conclusions. The addition of lime introduces a false stickiness.

The author, however, used the same concrete mix in the model as was intended for the permanent structure, namely, 705 lb. of cement per cubic yard, 1083 lb. of sand, 1838 lb. of gravel and 353 lb. of water. But for the tests in the model the size of the aggregates (both gravel and sand) were reduced to the scale of the model while keeping close to their sieve analysis in gradation of particle size, thus simulating as closely as possible the conditions in the tremie pipe to be met in the "full size" operation.

In a number of tests, a dosage of coloring matter was added to differentiate batches so as to indicate the effect of later deposits upon those preceding. Poured blocks of vari-colored concrete were saved, cured and sawed into sections for study (see Figs. 20 and 23).

When using the model a routine was developed as follows: The tremie was raised until the valve was above water. The valve was closed, and the tremie lowered to the bottom of the form, the portion below the valve was then full of water while that above the valve was full of air (Fig. 17). While the upper portion was being filled with freshly made concrete, compressed air was slowly admitted below the valve through a side inlet and it was seen to gently lower the water level in the tremie until all of the water was expelled. When done slowly, the water in the glass tremie went down quietly, its surface as smooth as a sheet of glass and no signs of turbulence were visible in the mass of water surrounding the tremie, nor was the gravel bottom disturbed. When the supply of compressed air was temporarily interrupted, the surface of the water in the tremie pipe simply stopped its descent and remained stationary and tranquil indicating perfect control at any stage, but when the full force of the compressed air was turned on suddenly, the water in the tremie was driven down and out with violence enough to disturb the gravel in the bottom and set up turbulent wave action in the surrounding mass of water just as a hydraulic ram would act and as the falling concrete in an open tremie had done at Pearl Harbor, but with one exception, namely, the turbulence subsided more quickly because the air, following the law of gases escaped by bubbling to the surface along and near the tremie, and did not have to dissipate its energies by transfer from molecule to molecule throughout the mass. Thus it was proven by

the visible action of the water in and around the glass tremie model, that the turbulence exists when rapid unwatering of the tremie pipe takes place, and it was also proven that there is no serious disturbance in the water surrounding the tremie when the lower portion of the pipe is unwatered by the slow, gentle application of compressed air.

Continuing the slow application of the compressed air, it is seen that eventually the water level in the tremie descends to the bottom

FIG. 20. Section of vari-colored concrete test block.

leaving the portion of the tremie below the valve void of water but filled with compressed air at a unit pressure equal to the hydrostatic head above the bottom of the form. If now the supply of compressed air is continued it will build up no more pressure but will escape around the periphery of the lower edge of the tremie pipe and rise to the surface along the line of least resistance, generally against or close to the outside of the tremie pipe. The bubbles coming to the surface are as a signal

to the observer that no more air is needed so its supply may be discontinued.

If during this interval sufficient concrete has been fed into the upper portion of the tremie one would see a vertical glass tremie pipe, its lower extremity resting on the rough pebble bottom of the form, its lower portion void of anything but compressed air, capillary attraction or surface tension holding the water to the outside of the lower edge of the tremie; a closed valve separating the lower from the upper portion of the tremie pipe, and the upper portion filled with freshly made concrete of the quality and consistency desired.

At this point, one may pause to consider the position of this valve in the height of the tremie pipe. Obviously, if the valve is placed too near the top, the weight of the column of concrete above it will be less than the pressure of the air beneath, so if the valve be opened the over-balancing air pressure would not allow the concrete to descend but would blow the concrete out the top of the tremie, relieving the air pressure and allowing the water to refill the entire tremie pipe up to its level in the surrounding water mass. If, on the contrary, the valve is placed too low in the pipe there will likely be a preponderance of weight in the mass of concrete above it, and when the valve is opened that portion of the weight of concrete overbalancing the air pressure will effectively increase the pressure causing a rapid exodus of air bubbles from beneath the lower edge of the tremie and some turbulence in the surrounding waters for a few minutes. But when the height of the valve is just right to balance the weight of the column of concrete above against the pressure of the air beneath it, the valve may be opened and no water will enter from the bottom nor will the concrete descend from the top, neither will it be blown out at the top. There will, however, be a slight escapement of air permeating up through the mass of plastic concrete which will relieve the pressure enough in time to accumulate a small puddle among the gravel in the bottom and also let a few fragments of loose concrete particles drop from the mass above. These are interesting phenomena to watch in the glass model, but it does not do to spend much time in this way lest the pressures and the chemical setting action in the concrete conspire to "freeze" the mass in its position.

However, in the state of balance just described, if there is added at the top of the tremie just enough additional concrete to overcome the friction against the walls of the upper portion of the tremie, the entire mass will fall to the bottom. But it is observed that when done in this way, the falling does not occur suddenly enmasse; instead the frictional bond takes a little time in giving way so that actually fragmentary masses or chunks of the concrete fall away first, descending through the air, pushing a little of it out to bubble up to the surrounding surface and then tardily, the rest of the mass of concrete descends leaving

the tremie still resting on the bottom but now with its valve open and concrete enough to slightly overbalance the hydrostatic pressure also resting on the bottom inside it. Concrete may then be added to fill the tremie to its top (Fig. 18).

The next step is to raise the tremie pipe off the bottom a little so that its contents may start flowing out against the water gradually displacing it in the form. When the above described operations are conducted in proper sequence and reasonable despatch there will be no trouble due to setting of the concrete, segregation, nor clogging in the tremie pipe. The experiments showed excellent results when lifting the pipe two or three diameters of the largest size of aggregate used in the mix.

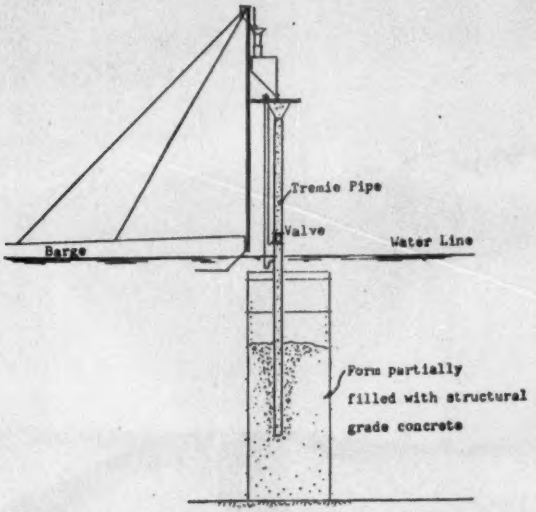


FIG. 21. Valved-tremie pipe concreting a submerged form.

Photographs show the concrete advancing against the water much as cooling lava proceeds along the ground. The first masses leaving the tremie seem to hug the bottom of the form and creep outward in a circular pattern which humps up if the head of concrete is given an appreciable differential over the hydrostatic head balance.

It was found by using successive batches made with contrasting colors, that the second lot pushes the first out toward the sides and corners of the form and that if these are not too distant some of the first batch may be pushed upward along the sides and corners (Fig. 23). This is believed due to a combination of causes. The water pressure tends to keep the oncoming fresh flow of concrete close to the bottom while the earlier deposit responding a bit more sluggishly as initial set begins tends to ride up since its density and declining plasticity give it greater

resistance to deformation. This tendency is soon interrupted by setting up in the first batch, by contact with reinforcing and form members and path of least resistance along the surface of contact between water and deposited concrete. It was found that little or no motion of the tremie was necessary, the form could readily be filled from one position. Later, while using this method for pouring the walls of Dry Docks No. 4 and No. 5 the lower end of the tremie was frequently maintained in one position until buried as much as 29 feet in the concrete (Fig. 21).

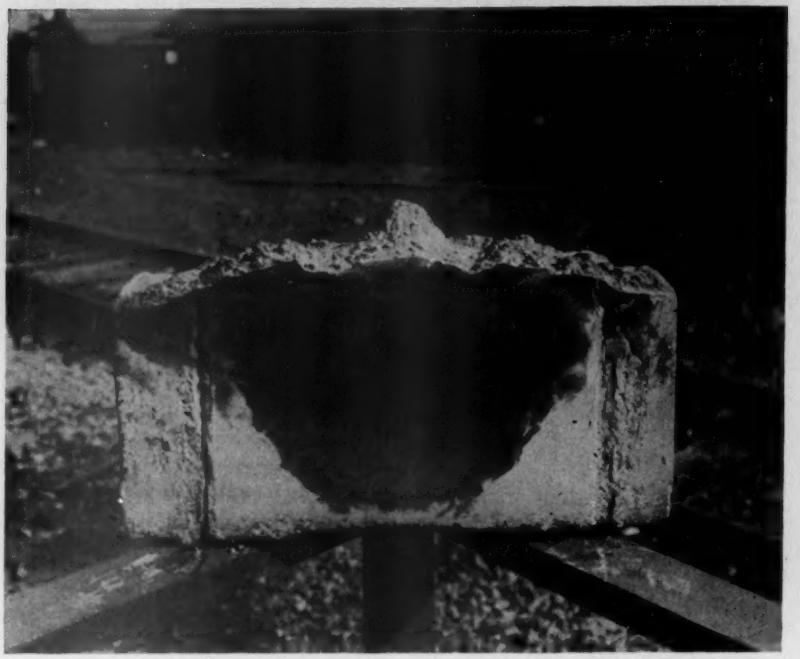


FIG. 22. Section of test block showing mound built up around a crater containing the tremie pipe.

After the second batch in the glass model, succeeding deposits tended to push previously placed batches outward and upward, and to build up a little mound around a crater containing the tremie pipe (Figs. 22 and 23). But always the water was clear and the surface of contact between water and concrete distinct and continuous indicating no loss of cement (see Fig. 20 which is a photograph taken through the water in the test box.).

When the tremie is raised to clear the concrete at the end of a "pour," most of its contents run out filling the crater, but when finally the lower edge is freed from the mass the water comes in and will

wash away the cement from the small volume of concrete caught in the pipe so there remains a little tell-tale mound of aggregate to indicate where the tremie was (Fig. 22) top center.

Having found this method workable, attention was directed to its use when contending with operating difficulties. If it were necessary to stop a pour at any time could it be resumed at will? A pour was begun in the glass model, stopped after depositing one batch for an interval of one hour. Then the work was resumed by proceeding

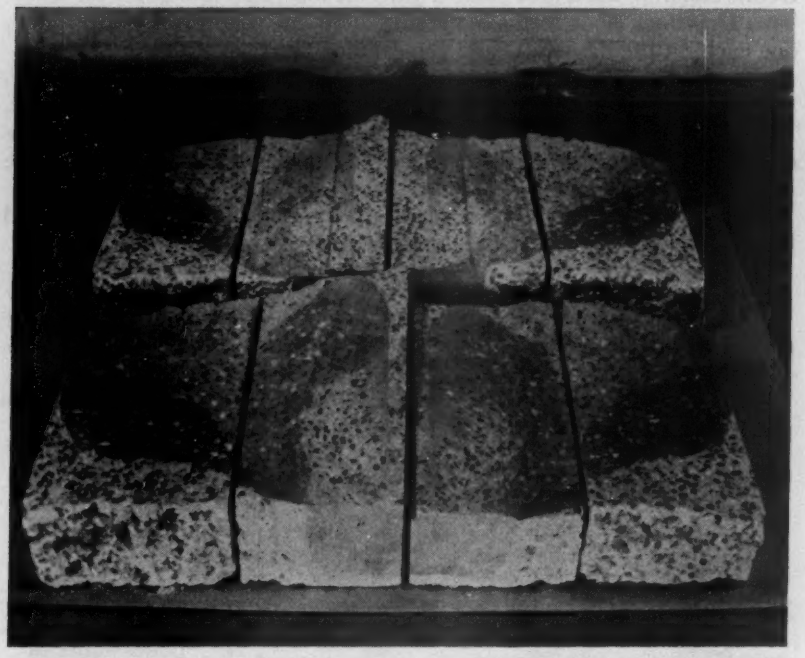


FIG. 23. Sawed test blocks showing mound of aggregate left when tremie pipe is pulled away from the mass of concrete at top center; also disposition of successive colored batches in the mass.

exactly as though commencing an entirely new pour. No difficulties were encountered. The water leaving the tremie tranquilly under the gentle steady pressure of the air did not disturb the partially set concrete previously placed. The same procedure tried after depositing three batches yielded precisely the same results. Later, the glass model tremie was used to teach crews of workmen the routine herein above described which they applied in full scale operation.

Earlier in this article "slump" was mentioned and its effect on plasticity of the concrete. While a good deal of plasticity is desirable in tremie work, it was found practical to run fairly stiff concretes,

that is concretes with 4½- to 5-in. slumps by resort to the practice of lubricating the tremie with an initial charge from which the coarse aggregate fraction is omitted from the mix.

The equipment used on the Philadelphia Docks was designed and built to work on this method and was operated on this routine.

The steel for forms and reinforcement cost $84.00 a ton for materials and $82.00 a ton for labor erected and sunk in place ready to receive the tremie concrete. ($6.32 total per cu. yd. of concrete.) The tremie concrete itself cost $5.56 a yard for materials and $0.89 for labor. Two Dry dock floor forms averaging 1000 cu. yd. were filled per day, one each on the day shift, and the evening shift.

The wall forms 44 ft. high averaging about 900 cu. yd. took 11 hr. to avoid excessive pressures from head due to freshly deposited concrete. In all 300,000 cu. yd. were poured in the docks by this method at Philadelphia. It was also used for concreting bridge piers and the Marine Railway foundations.

Because the tremie pipe is made up in sections it can be extended for use at much greater depths and for many other purposes.

RESULTS

The data appearing in the two tables in this section summarize the results of actual pourings, using the valved-tremie, on Dry Dock No. 4, Philadelphia Navy Yard, in 1941.

The cement content of mixes placed through the valved-tremie in pounds per batch of 1.2 cu. yd. are as follows:

Mix	Pounds per Batch
A	907
B	880
C	846
D	835
E	823

TABLE I.—*Valved-Tremie Concrete Placed in Dock Floor Forms.*

Pour No.	Date	Mix	Cu. Yd.	Ultimate Strength, psi.[1]
1	3- 4-41 A.M.	A	1259	3979+*
2	3- 6-41 A.M.	A	996	3979+
3	3- 7-41 A.M.	A	974	3979+
4	3-10-41 A.M.	A	967	3979+
5	3-11-41 A.M.	B	1039	3979+
6	3-13-41 A.M.	C	982	4850
7	3-12-41 A.M.	B/C	983	3840
8	3-13-41 P.M.	C	1101	4200
9	3-14-41 A.M.	C	951	4850
10	3-14-41 P.M.	C	865	4420
11	3-15-41 A.M.	C	967	4400
12	3-17-41 P.M.	C	977	3979+
13	3-17-41 A.M.	C	950	3979+
14	3-15-41 P.M.	C	1008	4420
15	3-18-41 A.M.	C	931	3979+
16	3-18-41 P.M.	C	1126	3600

TABLE I.—*Continued.*

Pour No.	Date	Mix	Cu. Yd.	Ultimate Strength, psi.[1]
17	3–19–41 A.M.	C	967	3979+
18	3–19–41 P.M.	C	980	3979+
19	3–20–41 A.M.	C	1004	3979+
20	3–20–41 P.M.	C	1018	3979+
21	3–24–41 A.M.	C	982	4350
22	3–21–41 P.M.	C	1029	4400
23	3–22–41 A.M.	C	985	4150
24	3–22–41 P.M.	C	1018	4360
25	3–24–41 A.M.	C	930	4550
26	3–24–41 P.M.	C	1019	4400
27	3–25–41 A.M.	C	982	4780
28	3–25–41 P.M.	C	1053	5000
29	3–26–41 A.M.	C	1013	4250
30	3–26–41 P.M.	C	1000	4550
31	3–27–41 A.M.	C	980	4340
32	3–27–41 P.M.	C	1071	4380
33	3–28–41 A.M.	C	1008	4660
34	3–28–41 P.M.	C	1028	4680
35	3–29–41 A.M.	C	1002	5200
36	3–29–41 P.M.	D	517	4560
37	3–31–41 A.M.	D	992	3979+
38	3–31–41 P.M.	D	1097	3979+
39	4– 1–41 A.M.	D	979	3979+
40	4– 1–41 P.M.	D	1043	3979+
41	4– 2–41 A.M.	D	971	3979+
42	4– 2–41 P.M.	C	985	3979+
43	4– 3–41 A.M.	E	962	3979+
44	4– 3–41 P.M.	D	1025	3979+
45	4– 4–41 A.M.	D	936	3660
46	4– 4–41 P.M.	E	969	3979+
47	4– 5–41 A.M.	E	934	3600
48	4– 5–41 P.M.	E	961	3979+
49	4– 7–41 A.M.	E	894	3490
50	4– 7–41 P.M.	E	971	3979+

NOTE: There were 98 floor "pours." Mix "E" was used consistently after Form No. 50 because it amply met the 3500 psi. strength specified and saved cement. Test cylinders broke from 3500 to 3979 + psi. All cylinders were 8" diam. × 16" long made and cured under U. S. Navy Standards conditions.

[1] Breaking strength of 28-day old cylinders.

* The limit of the local testing machine was 3979 psi. Cylinders marked 3979+ could not be broken on that machine.

TABLE II.—*Valved-Tremie Concrete Placed in Dock Wall Forms.*

Pour No.	Date	Mix	Cu. Yd.	Ultimate Strength, psi.
1	3–24–41	C	915	4720
2	3–25–41	C	879	4610
3	3–26–41	C	1246	4550
4	3–27–41	C	874	4580
5	3–28–41	C	940	4280
6	4– 5–41	E	893	3979+
7	4– 3–41	D	828	3550
8	4– 4–41	E	869	3700
9	4– 5–41	E	893	3810
10	4– 7–41	E	847	3700
11	4– 8–41	E	837	3690

NOTE: There were 65 wall "pours." Mix "E" was used after No. 9. Test cylinders broke from 3500 to 3979+ psi. To prevent overstraining the forms, walls were poured slowly, the tremie being as much as 29 ft. in the concrete at times.

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A NOTE ON THE SIMILARITY OF CERTAIN ATMOSPHERICS WAVEFORMS *

BY

W. F. ZETROUER [1] AND W. J. KESSLER [1]

ABSTRACT

This note reports a remarkable uniformity observed among waveforms of atmospherics associated with a common center of thunderstorm activity. Photographic results of observations during the day and night are reported. From 104 nighttime waveforms identifiable with a surface cold front extending over the midwestern states, 55 per cent are found to exhibit similar fine-structure characteristics. Of the 520 daytime waveforms associated with a surface cold front moving over the edge of the Gulf Stream, 41 per cent are classified as similar. The waveforms of the latter observation are further classified into two subgroups depending upon the polarity of the initial maxima of the observed waveforms.

During the course of an investigation of atmospherics at the University of Florida, remarkable similarities were observed between a large proportion of the waveforms of atmospherics from a given thunderstorm. These waveforms were recorded photographically from the screen of a driven-sweep oscillograph specifically designed for observing atmospherics. Two representative segments of the film record showing the nature of the waveforms normally observed with the oscillograph are shown in Fig. 1.

The material presented here describes the initial results of one phase of a comprehensive study of waveforms recorded from 1 October 1948 to 5 May 1949. The waveform data are in the form of daily photographic records of radiations from prevailing thunderstorms. Bearing indications for the waveforms were obtained from an instantaneous atmospherics direction finder. Each record consists of three lengths of 35-mm. film, corresponding to three one-minute observations, spaced over a 15-minute interval. Of the large number of waveforms recorded in this manner only those were compared which arrived from the same direction during a given observation. This selection process reduced the large volume of waveform data to groups identified with common sources.

The procedure used in studying the waveforms was as follows:

* This study constitutes the preliminary results of one phase of a comprehensive research program on the Direction Finding and Ranging on Atmospherics Under Research Contract No. W36-039-sc-38201 between the U. S. Army Signal Corps Engineering Laboratory and the Engineering and Industrial Experiment Station of the University of Florida.

[1] Assistant in Research and Assistant Research Engineer, respectively, Engineering and Industrial Experiment Station, University of Florida, Gainesville, Florida.

1. The three one-minute film strips constituting each photographic observation were scanned to determine the predominant direction or directions of arrival of atmospherics.

2. When such directions had been established for a particular observation, the waveforms were grouped with respect to direction of arrival.

3. Tracings of representative waveforms, corresponding to each predominant direction of arrival were made on translucent plastic cards.

4. Waveforms in each group were then critically compared, using the appropriate waveform tracing as a reference template.

The major criteria in comparing waveforms were the period increment (increase in successive half-cycle periods) and fine structure. Between waveforms corresponding to different sources there was in general sufficient difference in period increment to cause separation by about one-half cycle in three to five cycles.

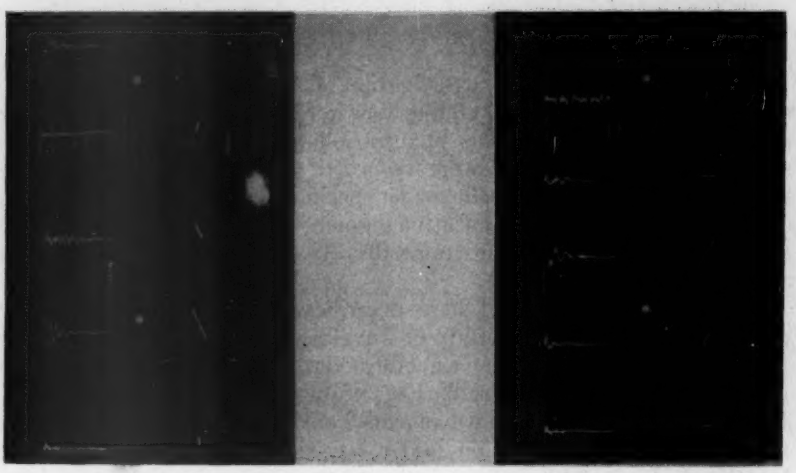

FIG. 1.

During examination of the records it became evident that the segment of the waveform photographed was not always the same. In comparing a waveform with the template it was sometimes necessary to displace the template laterally along the time-axis a half-cycle or a cycle to obtain agreement of form, demonstrating that on these waveforms the oscillograph sweep was not triggered during the first excursion. This was because the amplitude of this excursion was below the triggering threshold. For large initial excursions, however, substantially the entire leading edge of the waveform was recorded.

During the nighttime observation of 13 April 1949, 104 waveforms

were recorded in a 15-minute period from a westerly direction and were subsequently determined to have been associated with a frontal system extending over the mid-western states. A group of 57 of these waveforms or approximately 55 per cent of the number recorded were found to display a remarkable uniformity. Figure 2 shows in "stag-

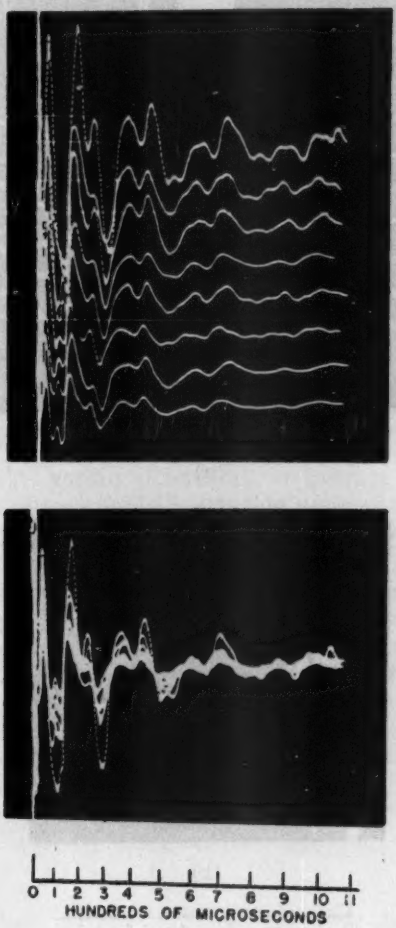

FIG. 2.

gered" and "composite" display a set of waveforms representative of this group. An interesting feature is the consistency in fine structure, in particular, the appearance of "notches" or depressions at the same points on each waveform. Because of the high writing speed the

initial excursions of the larger amplitude waveforms, while quite visible on the film record, did not reproduce satisfactorily. These excursions have been reinforced by dotted lines. It should be emphasized that the waveforms shown were scattered in time of occurrence over a

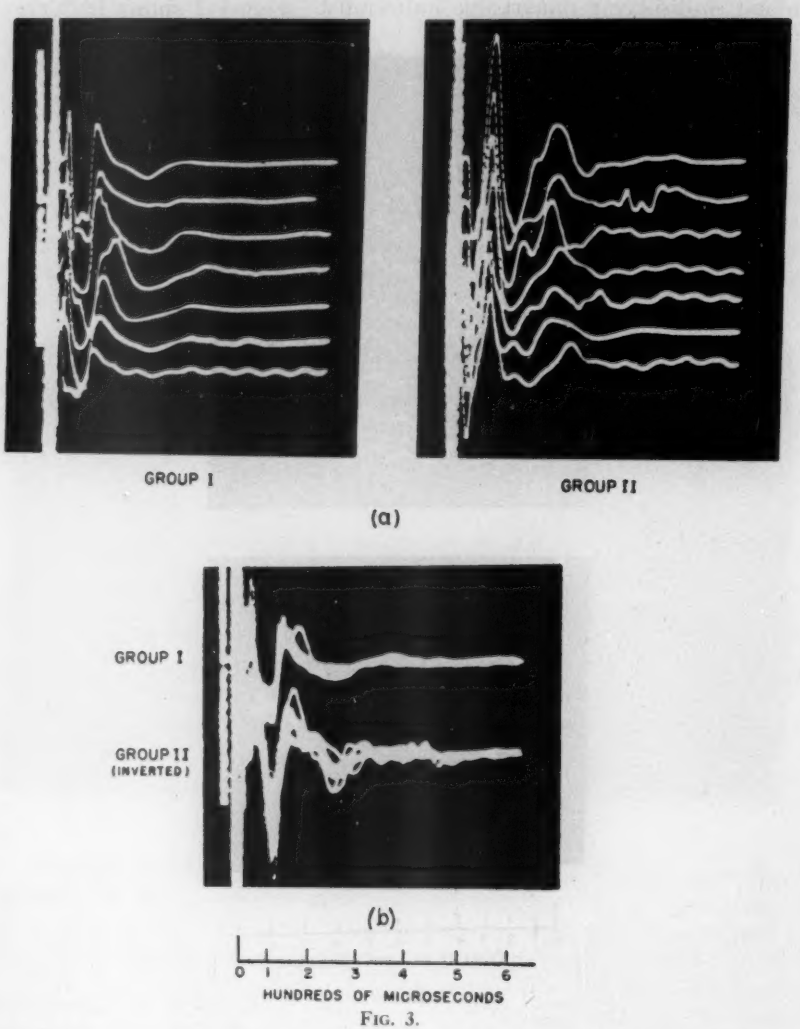

FIG. 3.

15-minute period and were not produced by successive discharges down the same ionized channel.

A source of considerable electrical activity was produced in the daylight hours of 10 March 1949 as a surface cold front passed the

edge of the Gulf Stream. A total of 520 waveforms from this source was recorded in a 15-minute period of which 213 or 41 per cent were similar in shape. Two groupings of waveforms are found in this record. Representative forms from each group are shown in Fig. 3 in staggered and composite arrangements. While waveforms of both groups exhibit the same number of half-periods, those in Group I display a positive first peak and those in Group II a negative first peak. Eighty per cent of the similar waveforms observed fall into Group I. It is found that if waveforms of Group II are inverted so that the first peak lies along that of Group I close matching is obtained. This is demonstrated in Fig. 3(*b*).

The results of this comparison study of atmospherics waveforms may be summarized as follows:

1. An appreciable percentage of the waveforms arriving from a particular direction at a particular time display essentially identical basic characteristics.
2. On records showing more than one general direction of arrival, the only tracing which would closely fit waveforms from a particular direction was the one made of a waveform from that direction, that is, the period increments and fine structure of atmospherics waveforms are not identical for all sources.

In view of the known differences in average cloud height and thunderstorm conditions prevailing during summer and winter periods, a seasonal variation in the waveforms may be expected. This factor and others, such as the nature of the meteorological conditions producing the atmospherics, distance between observing station and source, and the locale of the disturbance with reference to land or sea may influence the appearance of atmospherics waveforms. Investigations of waveform appearance in relation to these factors are currently in progress. It is expected that data of value in connection with these investigations will be obtained from continuous observations to be made on atmospherics from frontal systems forming to the west and moving eastward.

Dark Room Protection Against Chemicals.—Two products, MAGICVULC Insulator and MAGIC AIRVULC, made by the Magic Chemical Company, Brockton, Mass., give dark room protection against chemicals. They are liquid products, which, when brushed or sprayed on a surface, will dry to a tough, resilient, anti-corrosive rubber coating, that will last for years. These coatings fill a critical need during the current emergency because they extend the life of existing equipment and allow more economical replacement of needed equipment.

MAGICVULC Insulator and MAGIC AIRVULC have been used in the photographic industry for many years. Their specific application is in the coating and lining of photographic trays, tanks and table tops. These coatings form a long-lasting protection against the corrosive action of all chemicals used in the photographic industry. They are also excellent for water-proofing.

A pocket size atomic radiation detector developed by the Naval Research Laboratory, ONR, and the Bureau of Ships weighs two pounds, is powered by two flashlight batteries. The new radiac will probably replace a Geiger survey instrument which complete weighs 24 lb. The device is housed in a waterproof, shockproof plastic case, gives radiation readings on a visible scale ranging from .005 roentgens per hour (safe) to 500 r.p.h. (hot), utilizes subminiature cigarette size Geiger counter tube with sufficient current output to operate the radiac and a corona voltage regulator tube, together representing ten years of research.

Facsimile equipment under development by the Army Signal Corps will provide small front-line photos of newspaper quality anywhere in the world five minutes after the picture is taken. The new models will send pictures or maps, will scan at from 45 to 180 lines per minute, and will provide definition of 96, 200, and 300 lines per inch. In addition, both words and graphic material can be automatically reproduced on a mimeograph stencil, making hundreds of copies available within minutes. Three sets under consideration are a field reconnaissance set for 4 × 5 inch copy, a general purpose set for 8 × 12 inch material, and a weather map scanner for 18 inch copy. Still in planning stage is a set to accomodate 32 × 40 inch copy.

Retractable rail wheels on ambulance busses used in Korea permit evacuation of wounded from frontline areas all the way to station hospitals or hospital ships with a minimum of litter handling; when the bus operating in forward areas hauls its load to a railroad line, it merely drops the flanged guide wheels and takes to the rails, thus providing a smoother ride than the so-called Korean roads. The conversion job was effected by the 765th Transportation Railroad Shop Battalion.

New methods of extinguishing oil and gasoline fires, perfected by the Naval Research Laboratory of the Office of Naval Research after ten years of work, give the Navy the most efficient fire fighting systems in the world. For airplane carrier use, piped foam systems have been redesigned to permit instantaneous operation through push-button remote control. A new foam generating and pumping unit for shore fire fighting use features a triple pump unit powered by a 200 hp. motor which can deliver 2000 gallons per minute of foam at 60 psi. A special nozzle will release foam in a long distance straight stream, or protective cone-shaped curtain. Tank fires can be quenched by the subsurface injection method, using existing oil pipeline inlets as foam conduits.

THE SLOW DISCHARGE IN A NON-SELF-QUENCHING GEIGER-MUELLER COUNTER *

BY

W. E. RAMSEY [1]

INTRODUCTION

As an interpretation of the author's studies (1)[2] on the variation of wire potential with time, C. G. Montgomery and D. D. Montgomery (2) developed the now generally accepted theory of a self-quenching mechanism operating in all Geiger-Mueller counter action. For the so-called non-self-quenching gases they conceived the discharge process as made up of one or more self-terminating active periods marked by photon emission and ionization by collision. These very short active periods end when the field near the wire is sufficiently reduced by the wire's increasing negative charge. However, the potential change associated with each such period is almost entirely due to the inductive action of positive ions moving away from the wire after the quenching is completed. Thus all the negative charge which eventually goes to the wire is formed in a series of very short intervals separated in time from each other. Furthermore, the sum of all such short intervals is a small percentage of the total time the potential of the counter wire is changing.

The first active period (the only one in cases where the counter is "overshooting") involves the most vigorous ionization and the subsequent movement of the positive ion sheath, resulting from this ionization, involves the greatest rate of change of potential in the counter pulse. The movement of this first sheath results in what is called the fast part of the discharge. The movement of the subsequent sheaths, that follow the first inactive period (marked by the movement of charge but not by its liberation), together make up the slow discharge in a non-self-quenching mixture. Stever (3) has successfully applied this type of analysis to self-quenching mixtures (where never more than one active period is involved) and quantitatively related the "dead time" to the field about the wire, whose value is partially assigned by the position of the moving positive ion sheath.

In the original formulation of the picture (2) it was assumed that all discharges except the first were triggered when the positive ions reaching the cathode released electrons. While this phenomenon does

* Assisted by the joint program of the Office of Naval Research and the Atomic Energy Commission.

[1] Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

occur and is sufficient to initiate the multiple discharges, the measurements indicated here show that this mechanism is not necessary. When, as the first sheath moves outward, the field about the wire reaches the threshold value, any mechanism which provides a free electron will start a second discharge. Metastable atoms may provide such a free electron. However, even though such metastable states

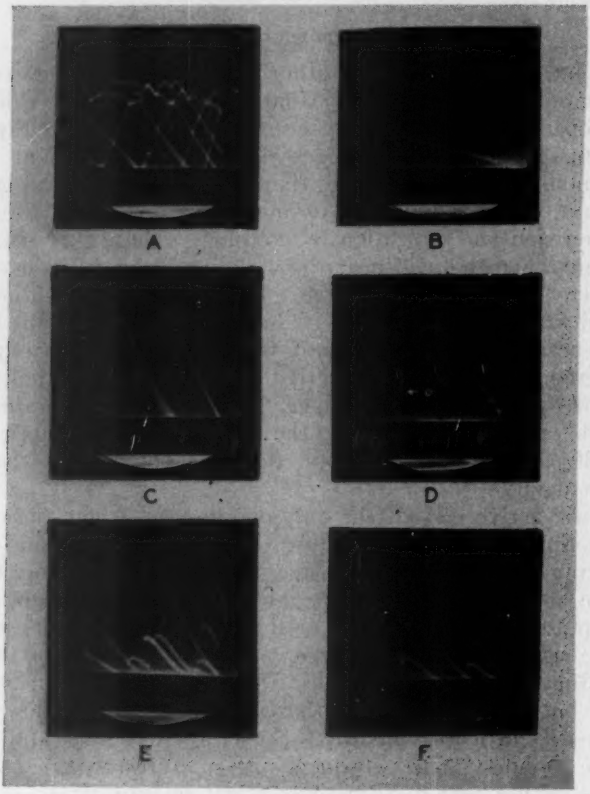

FIG. 1. Oscillograms illustrating single and multiple break phenomena in a non-self-quenching mixture. The recovery times characterize the constants of a coupled circuit and not those of the counter wire system. Refer to Introduction.

do not exist, the capture of a small percentage of the photoelectrons produced in the first active period provides a steady stream of negative ions, which in releasing their loosely held electrons, may serve to trigger subsequent active periods.

The picture as presented for a non-self-quenching mixture implies that if one measures the total negative charge on the wire system and in the gas as a function of time, it should be found increasing in steps.

The first step, due to the active period producing the fast breakdown, is the largest. The position in time and the magnitude of the remaining steps depend upon the mechanism initiating them. This step-by-step aspect of the discharge may be clearly seen from oscillograms of the discharge. Note, for instance, Fig. 1(*A*) and Fig. 1(*B*) where a number of such breaks (all a part of the slow discharge) are shown. This aspect may be obscured by a slow sweep or by the addition of external capacitors to the counter wire which greatly reduce the size of the steps. As an example, in Fig. 1(*C*), appear three pulses where the wire is slightly "overshooting" and the entire discharge is fast. In Fig. 1(*D*) an external capacitor has been added to the counter wire without in any way altering the other parameters. Here the fast part of the discharge ends at the point marked O and the steps making up the remainder of the discharge are so reduced as to give the impression of a continuous curve. Figure 1(*E*) and Fig. 1(*F*) indicate the uncertainty in stopping potential when, during the slow discharge, the potential difference between the wire system and the cathode approaches the threshold value. In one case a small break is observed at the end of the pulse.

PROCEDURE

Voltage variations while indicating a step-like process do not readily provide an accurate picture of the periods marked by active ionization and those in which movement of charge alone occur. To properly determine these active periods and the amount of ionization which they involve it is necessary to measure the total amount of negative charge on the wire system and in the gas for each instant of time during the discharge. In order to measure this quantity at a given instant it is necessary to interrupt all active discharge processes at that instant, collect the negative charge remaining in the gas and measure the consequent final potential of the wire system. This potential, with the previously determined capacitance provides the desired charge. This interruption of the active processes (if they exist) at the desired time was achieved by throwing the cylinder positive to a value which would permit no further gas amplification, but provide sufficient field for the subsequent collection of all charge in the counter volume. A small portion of the initial fast discharge was employed, through the operation of a delay circuit, to so change the cylinder potential at the required instant of time later. This alteration in potential was effected in about 0.6×10^{-6} seconds. After sufficient time had elapsed to permit a measurement of the wire potential all parameters were restored to their value at $t = 0$ by manually operated keys. It is obvious that this alteration of the cylinder potential induces a change of potential in the wire system. However, this change is constant for all values of the time and was carefully measured by triggering the circuit when the counter was free of all discharge processes. All data were corrected for this constant induced potential

before plotting the final curves. The high wire impedances necessary for this type of procedure were achieved by employing carefully constructed counters and by assigning the wire potential before each pulse with a key connected to the ground of the system. The alterations in wire potential were measured by an FP54 pliotron coupled through an air condenser to the wire system. The variation of potential induced in the wire system by the addition of capacitors of known value when a constant voltage pulse was applied to the counter cylinders provided the required capacity values.

CHARGE-TIME CURVES

Referring to Fig. 2 it is seen that following the first active period (the movement of whose positive ion sheath produces the fast alteration

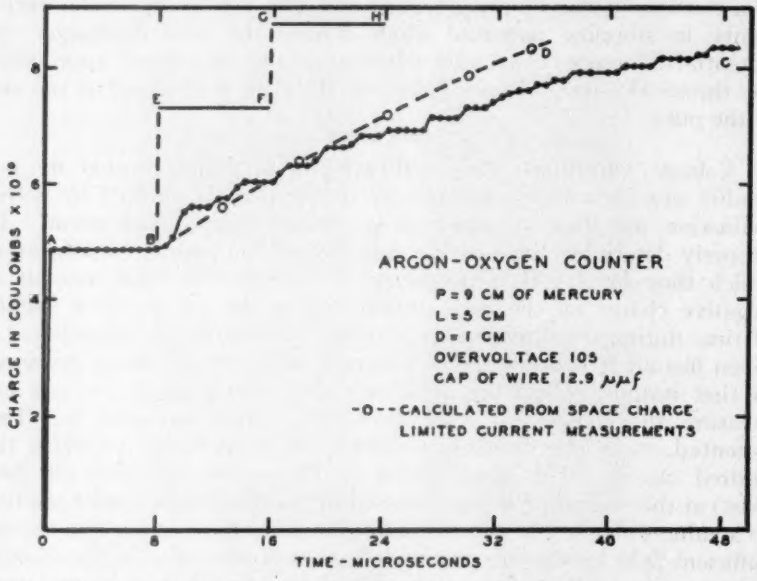

FIG. 2. Variation with time of the total negative charge on counter wire system and in the gas for a counter which is not "overshooting."

of wire potential) there are no ionization processes for a period of about 8.0×10^{-6} seconds. Then occur a series of small steps, not equally spaced in time nor simply related in magnitude. While there was a small fluctuation in values of the charge for a given time (for successive pulses) the points for this curve were surprisingly constant and the steps well defined. For large values of the time, where the potential across the counter was nearing the threshold value (not shown) on the curve this state of affairs altered. Here the charge measurements

were not constant for a given time as measured for different discharges. Oscillographic examination of the voltage variations in this region provides the explanation for these fluctuations. It is evident that free electrons do not exist in sufficient numbers to maintain the step-by-step process and the whole discharge is disposed to stop. Occasionally clean-cut multiple breaks were seen, separated by much longer time intervals.

Figure 3 indicates the marked extent to which the onset of the slow discharge may be altered by the addition of external capacitors

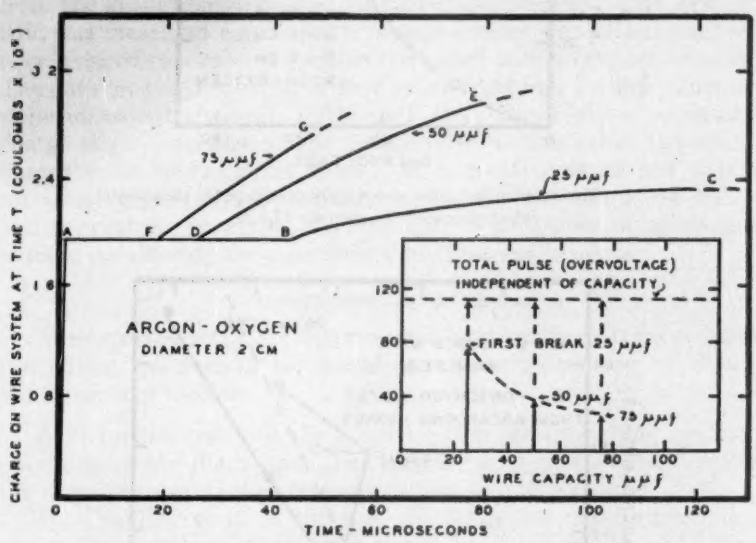

FIG. 3. Charge-Time curves showing the alteration in the onset of the slow discharge produced by connecting additional capacitors between counter wire system and ground. All other parameters are unaltered.

between the wire system and ground, all other parameters remaining fixed. For these curves the multiple steps were small and smooth curves were drawn through the mean of measured points. It may be stated, however, that the number of steps for a given time interval increased as, with the increasing capacitance of the wire system, the time of initiation of the slow discharge was reduced. This was particularly noticeable near the threshold times indicated by *F*, *D*, *B*. Although not as clean-cut this alteration in the time when the slow discharge starts may be observed from direct oscillographic observation of the potential pulse if a suitable sweep frequency is employed.

Figure 4 gives pulse size data for the counter used in taking the measurements shown in Fig. 2. Although the ordinates represent the maximum voltage swing due to the first active period it is obvious

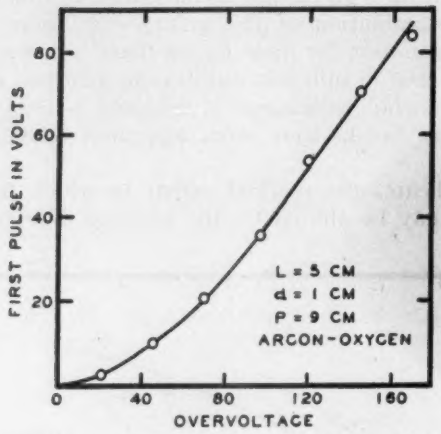

FIG. 4. Variation of fast pulse size with overvoltage for the counter which provided the data for Fig. 2.

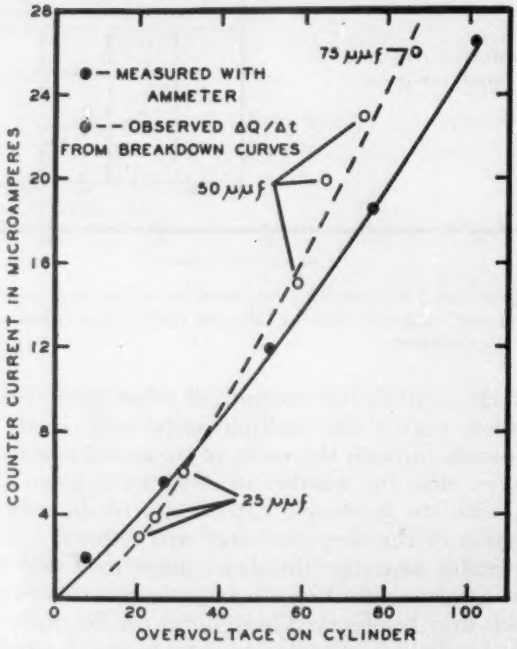

FIG. 5. Data showing the extent to which the slow discharge currents may be anticipated from steady space charge limited current measurements.

that this curve may be employed to calculate the amount of charge for successive active periods *provided each such period occurs after preceding positive ion sheaths have reached the cathode.*

A consideration of the charge formed during the first active period, which for this mixture is terminated in a time not greater than 2.0×10^{-7} seconds (1), leads to currents a hundred times greater than the steady space charge limited current for the initial overvoltage. However, as shown in Fig. 5 and by *BD* Fig. 2, the current flowing in the slow discharge of a single pulse may be determined approximately from the space charge limited current characteristic. This characteristic was measured employing a microammeter with all external resistance reduced to a value negligible compared to the counter impedance. The data for the dotted curve were taken from Fig. 3 using values of the slope measured along *BC*, *DE*, and *FG*. For a given value of the charge the overvoltage at the associated time was estimated from the known value of the capacitance. It is to be pointed out that this procedure gives only approximate values for the charge on the wire and overvoltage, not the exact values. The degree of agreement is marked considering the uncertainty in these assignments.

CONCLUSIONS AND DISCUSSION

The experimental material presented here justifies certain deductions concerning the over-all picture of the discharge process for this non-self-quenching mixture.

I. It further confirms the existence of a self-quenching mechanism operating in the discharge. The step by step characteristic indicates the repeated operation of this mechanism in a single pulse.

II. That the steps in the slow discharge are more numerous and of smaller amplitude than they would be if triggered only after the positive ion sheaths have reached the cathode.

III. That the free electrons which trigger the successive steps exist in sufficient numbers to insure a discharge when the field about the wire attains the proper value. Only near the end of the slow discharge is this untrue and wide fluctuations can occur in the form of the pulse.

IV. That while space charge limited current measurements bear no relationship to the fast discharge, such currents may be used to anticipate the amplitude and duration of the slow discharge.

For conclusions II and III it is necessary to refer to Figs. 2, 3, and 4. If it be assumed that at *B* (Fig. 2) the first positive ion sheath had reached the cathode, the difference in potential between the counter wire and cylinder at this instant must have been 67 volts. When a discharge subsequently occurred it would have involved, as indicated in Fig. 4, an ultimate change in the potential of the wire system of 20 volts and a *sudden* increase in the charge *BE*.

Actually nine distinct steps were required to alter the charge by the

amount *BE*. This observation indicates that the field at the wire was less intense than the assumption would warrant, or in other words that the first sheath was still moving outward toward the cylinder. Furthermore the large alterations which can be effected in the time interval before the onset of the slow discharge (Fig. 3) are not consistent with the assumption that the arrival of the first positive ion sheath at the cathode is marked by the liberation of electrons which precipitate the slow discharge. The transit time of this sheath across the counter would be altered somewhat by the external capacitors but no change such as is represented by the difference between *B* and *F* could be expected. The sizes of the steps in the slow discharge assign a field intensity about the wire which is near the threshold value. The fact that the steps are not as abrupt as the first can be explained by assuming that each is made up of a number of small discharges which do not necessarily spread the full length of the counter. Such behavior is observed upon oscillographic examination of the pulses for cathode voltages near the starting potential. Here the pulses are single, but differ greatly in size as they must if variable portions of the wire are involved in the discharges. In the case under discussion (Fig. 2) such small discharges continue, sustained by the increasing field due to the motion of the first sheath and triggered by the available free electrons. The end of a step marks the instant at which the combined negative charge on the wire once more quenches active ionization. Then, as indicated by the flat portion of the steps, no change of charge is observed until the motion of all positive ions in the gas has permitted the restoration of the field. The steps seen in Fig. 2 would not be reproducible were it not for the fact that free electrons exist in sufficient numbers to insure a discharge at the appropriate instant of time. Otherwise the wide statistical fluctuations observed near the end of the slow discharge (when the field is also near the threshold value) would characterize the situation at its beginning.

The free electrons required to sustain the slow discharge may be provided by metastable atoms in the gas, by the liberation of electrons which, freed from the cylinder or gas in the first active period, spend a portion of their transit life in the captured state, and (for later portions of the slow discharge) by electrons liberated from the cylinder by positive ions. Studies have been made of electron capture and retarded discharge phenomena using this mixture and others containing oxygen (**4, 5, 6, 7, 8**). It is important to point out therefore that in the absence of all other mechanisms the liberation of captured electrons would sustain the slow discharge. If for every 10^5 electrons arriving at the wire in the first active period only one is retarded by capture, several would be released for every 10^{-7} second interval of time from $t = 0$ to $t = 10^{-4}$ seconds. The slow discharge itself, in much less than 10^{-4} seconds, provides an additional source of negative ions streaming toward the counter wire.

The charge-time curves may be used to indicate the difference in the over-all discharge pictures for self-quenching and non-self-quenching mixtures.

The term "non-self-quenching" arose initially because the potential of the wire had to be assigned through a high resistance. This procedure prevented charge from leaving the wire system until the slow discharge was completed. Completion occurs when no mechanism exists to provide free electrons—a state achieved as the field about the wire approaches the threshold value in the absence of positive ions in the gas. Loss of charge through the wire resistance at too great a rate prevents the achievement of this state and the discharge continues. Thus the slow discharge may be self-perpetuating although made up of self-quenched stages.

For a self-quenching mixture there is no slow discharge, and hence the space charge limited current is zero over the whole working range of cathode potentials. The charge as measured here is constant for all times after the first active period. The restoration of the field to the threshold value by the moving positive ion sheath now marks the end of counter dead time and another discharge, if it occurs, indicates that another ionizing particle has entered the tube. In the non-self-quenching mixture the slow discharge may be eliminated by the use of a cutoff circuit, such as the Neher-Harper, but in no case can the counter be restored to operation in times as short as the dead times indicated in Figs. 2 and 3. The counter potential cannot be restored until the elapse of a sufficient interval to sweep from the gas all particles capable of freeing electrons without the assistance of another ionzing ray.

Acknowledgment

It is a pleasure to thank Dr. W. F. G. Swann, Dr. W. E. Danforth, and Dr. C. E. Mandeville for helpful discussions covering the material presented here.

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Magnetic Tape Recording Head (*Electronic Engineering*, Vol. XXIII, No. 280).—Messrs. Phidelity Magnetic Products, Ltd., have started production on a range of magnetic tape recording heads which are suitable for a requirement of the recorder manufacturer and the home constructor.

The heads are made up of laminations of magnetic steel, worked to close precision limits. The gap depth is held to the minimum figure possible, and the windings are specially designed for maximum flux density at the smallest audio currents. All heads are mounted in non-magnetic holders designed for single screw fixing, and are available in the following types: Type SA which is a dual purpose record and playback head with a gap of .001 inch; Type SE is a supersonic erase head suitable for low coercivity tape, with a gap of .0005 inch; Type SR is a recording head with separate audio and bias windings, with a gap of .001 inch; and Type SP is a very high fidelity playback head, with a gap of .00025 inch. All four types have low impedance winding. All heads are for full $\frac{1}{4}$ inch track, but half track heads to the same specification can be supplied.

Dual-Spray Gun (*Modern Plastics*, Vol. 28, No. 10).—Materials which cure quickly when combined gain added life through use of a new paint-type spray gun that handles two solutions at the same time. The gun, Model 2S, is a product of Schori Process Div., Ferro-Co. Corp., 8–11 43rd Rd., Long Island City 1, N. Y., and was developed to handle materials that are stable in themselves, but that cure when mixed. Formulations can be sprayed that will be tack-free in 10 minutes. The Schori unit uses two pots and a spray gun with two nozzles. This keeps the solutions apart until they become atomized.

Special polyester resin formulations have been developed for use with this gun. For optimum results, a compressor should be used which delivers at least 15 cu. ft. of air per min. with a maximum line pressure of 70 pounds. Greater line pressure will increase the amount of resin mix sprayed. Applying line pressure directly to the gun is the preferred procedure.

A gust-alleviator developed by Air Materiel Command and Douglas Aircraft engineers will give commercial planes higher speed, more comfortable flying, will increase range or payload of bombers and cargo planes. The device, a simple mechanical linkage hooked up to plane's ailerons, has been satisfactorily flight-tested in a C-47, is completely automatic in operation, in no way affects pilot control of ailerons. Engineers estimate gust-alleviators will permit lighter plane structure, as much as 2–3000 pounds in 50 ton plane, increase level flight high speed as much as 75 mph. over top 300 mph.

All's quiet at the Naval Acoustical Laboratory, Annapolis, where a new wrinkle in soundproofing has produced the most sensitive sound-free room ever built. Fiber glass with glass cloth cover arranged in accordion-like folds makes it possible to study sound ranging from 60 to 8000 cycles per second; tests in one room in no way interfere with work going on in two more similar rooms. Engineers literally turned the building inside out to keep it quiet; all structural framework is outside the building; interior walls are perfectly flat; roof is suspended from beams.

THE SOLUTION OF BOUNDARY VALUE PROBLEMS BY MULTIPLE LAPLACE TRANSFORMATIONS

BY

THELMA A. ESTRIN [1] AND THOMAS JAMES HIGGINS [1]

ABSTRACT

By use of the multiple Laplace transform a partial differential equation and its associated boundary conditions characterizing a boundary value problem in n independent real variables can be transferred directly into an algebraic equation in n independent complex variables. This algebraic equation can be solved for the multiple transform of the solution of the boundary value problem. Multiple inversion of this transform then gives the desired solution. The general theory underlying such solution of boundary value problems in two and three independent variables is advanced in detail. Use of this theory is illustrated by solution of two specific problems.

1. INTRODUCTION

In a recent paper (1),[2] one of the present authors emphasized the unsatisfactory state of the operational calculus in application to the solution of boundary value problems characterized by partial differential equations; stressed the need for a correct, well integrated account of the operational theory available for such problems; and pressed the desirability of further development of this theory in terms of multiple Laplace transformations.

Double Laplace transforms were introduced by Van der Pol (2). They have been used by Humbert (3) in his study of hypergeometric functions; by Jaeger (4) to solve boundary value problems in heat conduction; by Shastre (5) and doubtless by others. Despite this use, no systematic account of the general theory of an operational calculus using Laplace transforms of double and higher multiplicity is to be found in the literature. The purpose of this paper is to help fill this gap. It comprises two major parts: statement of the theory underlining the solution of boundary value problems by multiple Laplace transformations; illustration of the use of this theory through solution of two problems, one in electrostatics, the other in heat conduction.

The multiple Laplace transform relates a function $f(x_1, \cdots, x_n)$ of the n independent real variables, $x_1, \cdots, x_n$, to a function $\bar{f}_n(p_1, \cdots, p_n)$ of the n independent complex variables $p_1, \cdots, p_n$ through the equation:

$$\bar{f}_n(p_1, \cdots, p_n) = \int_0^\infty e^{-p_n x_n} \cdots \int_0^\infty e^{-p_1 x_1} f(x_1, \cdots, x_n) dx_1, \cdots, dx_n. \quad (1)$$

[1] Instructor in Electrical Engineering and Professor of Electrical Engineering, respectively, University of Wisconsin, Madison, Wis.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

The function defined by (1) is termed the multiple Laplace transform of $f(x_1, \cdots, x_n)$. Conversely, if the multiple Laplace transform is known, its inverse is given by the multiple inversion integral:

$$f(x_1, \cdots, x_n) = \frac{1}{2\pi i}\int_{\text{Br.}} e^{x_n p_n} \cdots \frac{1}{2\pi i}\int_{\text{Br.}} e^{x_1 p_1} \bar{f}_n(p_1, \cdots, p_n)\, dp_1, \cdots, dp_n. \quad (2)$$

Herein Br. designates the appropriate Bromwich contour in the plane of integration.

Applying the n-fold integration of (1) to each term of an nth order partial differential equation with constant coefficients yields an nth degree algebraic equation. The transform of the solution of the partial differential equation is readily obtained from this algebraic equation. Inverting this transform through use of (2) yields the solution of the partial differential equation.

The usual operational method of solving boundary value problems in time and space variables transforms the partial differential equation and its boundary conditions with respect to time, the space variables being held constant; solves the resulting ordinary or partial differential equation by classical means, the transform parameter being treated as a constant; recognizes the resulting expression in the transform parameter as the single Laplace transform of the desired solution; and effects the required inversion. Obviously the use of a single Laplace transformation in this manner is not as advantageous as it is in the solution of ordinary differential equations, because an ordinary or partial differential equation yet remains to be solved after the single transformation.

The essential advantage of the multiple Laplace approach is that it eliminates conjunction of classical differential equation theory with Laplace transform theory. Thus, application of (1) to a partial differential equation in n real variables transforms it to an algebraic equation in n complex variables; whence inversion of this transform equation by the use of (2) yields the desired solution. The analytical difficulty of evaluating multiple inverse transforms increases with the number of independent variables, to the end that a fairly comprehensive knowledge of contour integration may be needed to effect the final solution. However, as multiple transform theory comes into greater use, it is to be expected that transform pairs for the more commonly encountered functions of two, three, and four variables will be evaluated and compiled in tables. With such tables available, the actual evaluation of the inversion integral is obviated and the solution of boundary value problems in several variables is reduced to a relatively routine procedure.

2. SINGLE LAPLACE TRANSFORMATIONS OF A FUNCTION OF SEVERAL VARIABLES

The Laplace transform with respect to x of $f(x,y,z,t)$ is defined by

$$L_x[f(x,y,z,t)] = \bar{f}(p,y,z,t) = \int_0^\infty e^{-px} f(x,y,z,t)dx. \quad (3)$$

The symbol $L_x[f(x,y,z,t)]$ indicates the integral operation of (3), the subscript x on L indicating which variable is undergoing transformation. In the alternative symbol $\bar{f}(p,y,z,t)$ the bar indicates a single transformation and the complex variable p replacing the real variable x establishes x as the variable of transformation. If the infinite integral of (3) exists, it transforms a function of the real variables x,y,z, and t to a function of the complex variable p and the real variables y,z, and t. Analogously, the Laplace transform of this same function $f(x,y,z,t)$ with respect to t is given by

$$L_t[f(x,y,z,t)] = \bar{f}(x,y,z,s) = \int_0^\infty e^{-st} f(x,y,z,t)dt. \tag{4}$$

Conversely, when the transform $\bar{f}(p,y,z,t)$ is known, the corresponding inverse function $f(x,y,z,t)$ is given by the Fourier-Mellin inversion integral

$$f(x,y,z,t) = L^{-1}{}_p[\bar{f}(p,y,z,t)] = \frac{1}{2\pi i}\int_{Br.} e^{zp}\bar{f}(p,y,z,t)dp. \tag{5}$$

The subscript p on the inversion symbol L^{-1} indicates the inversion integral is to be evaluated in the p plane. This is also apparent in that p is the only complex variable appearing in the parenthesis. Analogously, if the given transform is $\bar{f}(x,y,z,s)$, the inversion integral to be evaluated in the s plane is,

$$f(x,y,z,t) = L^{-1}{}_s[\bar{f}(x,y,z,s)] = \frac{1}{2\pi i}\int_{Br.} e^{st}\bar{f}(x,y,z,s)ds. \tag{6}$$

In general, when transforming from a real variable to a complex variable the interchanges to be used are

$$\begin{aligned} x &\to p \\ y &\to q \\ z &\to r \\ t &\to s. \end{aligned} \tag{7}$$

The transform of the nth unmixed partial derivative of a function with respect to the variable of differentiation is given by

$$L_x\left[\frac{\partial^n f(x,y,z,t)}{\partial x^n}\right] = p^n\bar{f}(p,y,z,t) - p^{n-1}f(o,y,z,t)\cdots - p\frac{\partial^{n-2}f(o,y,z,t)}{\partial x^{n-2}} - \frac{\partial^{n-1}f(o,y,z,t)}{\partial x^{n-1}}. \tag{8}$$

The transform of the nth unmixed partial derivative with respect to a variable other than the one of differentiation is, typically,

$$L_z\left[\frac{\partial^n f(x,y,z,t)}{\partial z^n}\right] = \frac{\partial^n \bar{f}(p,y,z,t)}{\partial z^n}. \tag{9}$$

3. MULTIPLE LAPLACE TRANSFORMS OF FUNCTIONS OF SEVERAL VARIABLES

Equations 3 to 9 for the single Laplace transforms of a function and its derivatives are now to be utilized to obtain the multiple Laplace transforms of this function and its derivatives.

Consider a function $f(x,t)$. According to (4) this function is transformed to $\bar{f}(x, s)$ through

$$L_t[f(x,t)] = \bar{f}(x,s) = \int_0^\infty e^{-st} f(x,t)dt. \tag{10}$$

This singly transformed function $\bar{f}(x,s)$ can be transformed again with respect to x according to (3)

$$L_x[\bar{f}(x,s)] = \int_0^\infty e^{-px} \bar{f}(x,s)dx. \tag{11}$$

This successive transformation is symbolized by $L_xL_t[f(x,t)]$ and can be indicated in one equation as

$$L_xL_t[f(x,t)] = \int_0^\infty e^{-px} \int_0^\infty e^{-st} f(x,t)dt\,dx. \tag{12}$$

If it is assumed that $f(x,t)$ satisfies conditions under which the order of transformation with respect to x and t can be interchanged, then

$$\int_0^\infty e^{-px} \int_0^\infty e^{-st} f(x,t)dt\,dx = \int_0^\infty e^{-st} \int_0^\infty e^{-px} f(x,t)dx\,dt. \tag{13}$$

If (13) is satisfied this double transformation may be written symbolically as

$$L_xL_t[f(x,t)] = L_tL_x[f(x,t)] \equiv \bar{\bar{f}}(p,s) \equiv M[f(x,t)]. \tag{14}$$

The new notations, $\bar{\bar{f}}(p,s)$ or $M[f(x,t)]$, do not indicate the order of transformation, but are more compact and, hence, are used when the order of transformation is interchangeable.

More generally, consider a function $f(x,y,z,t)$ of the four independent real variables x,y,z, and t. The four-fold transform of this function involves a quadruple transformation under which the four real variables are replaced by the four associated complex variables of (7). This quadruple transformation can be effected in twenty-four different orders. Hence, $f(x,y,z,t)$ has twenty-four possible quadruple transforms. If these are identical, the multiple transform is given by any of the twenty-four possibilities, one of which is

$$M[f(x,y,z,t)] = \bar{\bar{\bar{\bar{f}}}}(p,q,r,s)$$
$$= \int_0^\infty e^{-st} \int_0^\infty e^{-rz} \int_0^\infty e^{-qy} \int_0^\infty e^{-px} f(x,y,z,t)dx\,dy\,dz\,dt. \tag{15}$$

In general, the term multiple Laplace transform shall designate the transform of a function of two or more variables, the order of trans-

formation being immaterial—which is the case for most functions encountered in practice.

4. MULTIPLE INVERSE TRANSFORMS OF FUNCTIONS OF SEVERAL VARIABLES

The inverse transform $f(x,t)$ of a singly transformed function $\bar{f}(p,t)$ can be obtained from (5). Similarly the inverse transform with respect to p of the doubly transformed function $\bar{\bar{f}}(p,s)$ is given by

$$L^{-1}{}_p[\bar{\bar{f}}(p,s)] = \frac{1}{2\pi i}\int_{\text{Br.}} e^{xp}\bar{\bar{f}}(p,s)dp. \tag{16}$$

This inversion yields the singly transformed function $\bar{f}(x,s)$. A second inversion with respect to s yields the original function $f(x,t)$

$$L^{-1}{}_t[\bar{f}(x,s)] = \frac{1}{2\pi i}\int_{\text{Br.}} e^{ts}\bar{f}(x,s)ds. \tag{17}$$

The successive inversions of (16) and (17) are encompassed by

$$L^{-1}{}_t L^{-1}{}_p[\bar{\bar{f}}(p,s)] = \frac{1}{2\pi i}\int_{\text{Br.}} e^{ts}\frac{1}{2\pi i}\int_{\text{Br.}} e^{xp}\bar{\bar{f}}(p,s)dp\,ds. \tag{18}$$

If it is assumed that $\bar{\bar{f}}(p,s)$ satisfies conditions under which the order of transformation can be interchanged to yield the same original function, then

$$\frac{1}{2\pi i}\int_{\text{Br.}} e^{ts}\frac{1}{2\pi i}\int_{\text{Br.}} e^{xp}\bar{\bar{f}}(p,s)dp\,ds = \frac{1}{2\pi i}\int_{\text{Br.}} e^{xp}\frac{1}{2\pi i}\int_{\text{Br.}} e^{ts}\bar{\bar{f}}(p,s)ds\,dp. \tag{19}$$

This successive inversion is indicated symbolically as

$$L^{-1}{}_t L^{-1}{}_p[\bar{\bar{f}}(p,s)] = L^{-1}{}_p L^{-1}{}_t[\bar{\bar{f}}(p,s)] = M^{-1}[\bar{\bar{f}}(p,s)]. \tag{20}$$

The new operator M^{-1} indicates the associated function is to be inverted with respect to each of its complex variables in turn, and that any of the possible orders of inversion will yield the same function.

Analogously, the multiple inverse transform $f(x,y,z,t)$ of a function $\bar{\bar{\bar{f}}}(p,q,r,s)$ is

$$M^{-1}[\bar{\bar{\bar{f}}}(p,q,r,s)] = f(x,y,z,t)$$
$$= \frac{1}{2\pi i}\int_{\text{Br.}} e^{ts}\frac{1}{2\pi i}\int_{\text{Br.}} e^{zr}\frac{1}{2\pi i}\int_{\text{Br.}} e^{yq}\frac{1}{2\pi i}\int_{\text{Br.}} e^{xp}\bar{\bar{\bar{f}}}(p,q,r,s)dp\,dq\,dr\,ds. \tag{21}$$

5. MULTIPLE TRANSFORMS OF PARTIAL DERIVATIVES

The application of multiple Laplace transform theory to the solution of partial differential equations requires knowledge of the multiple

transform of a partial derivative. Illustratively, consider the multiple transform of $\frac{\partial^2 f(x,t)}{\partial t^2}$

$$M\left[\frac{\partial^2 f(x,t)}{\partial t^2}\right] = L_x L_t \frac{\partial^2 f(x,t)}{\partial t^2} = \int_0^\infty e^{-px} \int_0^\infty e^{-st} \frac{\partial^2 f(x,t)}{\partial t^2}\, dt\, dx. \quad (22)$$

The first indicated transformation with respect to t can be determined from (8)

$$\int_0^\infty e^{-st} \frac{\partial^2 f(x,t)}{\partial t^2}\, dt = L_t \frac{\partial^2 f(x,t)}{\partial t^2} = s^2 \bar{f}(x,s) - sf(x,o) - \frac{\partial f(x,o)}{\partial t}. \quad (23)$$

Substituting (23) in (22) yields

$$M\left[\frac{\partial^2 f(x,t)}{\partial t^2}\right] = \int_0^\infty e^{-px} \left[s^2 \bar{f}(x,s) - sf(x,o) - \frac{\partial f(x,o)}{\partial t}\right] dx. \quad (24)$$

Applying (3) and (9) to (24) yields

$$M\left[\frac{\partial^2 f(x,t)}{\partial t^2}\right] = s^2 \bar{\bar{f}}(p,s) - s\bar{f}(p,o) - \frac{\partial \bar{f}(p,o)}{\partial t}. \quad (25)$$

The multiple transform of the partial derivative, $\frac{\partial^2 f(x,t)}{\partial t^2}$, has thus been deduced from single Laplace transformation theorems. Confirmatively, (25) can be obtained by direct integration of the double integral (22).

Comparison of (25) and (23) suggests that it is possible to determine the multiple transform of a partial derivative from inspection of its single transform with respect to the variable of differentiation. Thus (25) follows from (23) if in each term of (23) the real variable x is replaced by its associated complex variable p and a bar is placed over the term to further indicate this replacement. In further illustration, consider determination of $M\left[\frac{\partial^n f(x,t)}{\partial t^n}\right]$. In accordance with (8) the single Laplace transform of this nth partial derivative with respect to the variable of differentiation t is

$$L_t\left[\frac{\partial^n f(x,t)}{\partial t^n}\right] = s^n \bar{f}(x,s) - s^{n-1} f(x,0) \cdots - s\frac{\partial^{n-2} f(x,0)}{\partial t^{n-2}} - \frac{\partial^{n-1} f(x,0)}{\partial t^{n-1}}. \quad (26)$$

Replacing x by its associated p in each term of (26) and putting a bar

over the terms yields the multiple transform of $\frac{\partial^n f(x,t)}{\partial t^n}$.

$$M\left[\frac{\partial^n f(x,t)}{\partial t^n}\right] = s^n \bar{\bar{f}}(p,s) - s^{n-1}\bar{\bar{f}}(p,0)\cdots - s\frac{\partial^{n-2}\bar{\bar{f}}(p,0)}{\partial t^{n-2}} - \frac{\partial^{n-1}\bar{\bar{f}}(p,0)}{\partial t^{n-1}}. \quad (27)$$

More generally, this procedure for deducing the multiple transform of an unmixed partial derivative of a function of two variables is applicable to the unmixed partial derivative of a function of any number of independent variables. In illustration, consider determination of the multiple transform of $\frac{\partial^n f(x,y,z,t)}{\partial z^n}$. The single transform with respect to the variable of differentiation z is given by (8) as

$$L_z\left[\frac{\partial^n f(x,y,z,t)}{\partial z^n}\right] = r^n \bar{f}(x,y,r,t) - r^{n-1} f(x,y,0,t)\cdots - r\frac{\partial^{n-2} f(x,y,0,t)}{\partial z^{n-2}} - \frac{\partial^{n-1} f(x,y,0,t)}{\partial z^{n-1}}. \quad (28)$$

Replacing each real variable by its associated complex variable as given in (7) and adding one bar for every real variable so replaced yields the desired multiple transform

$$M\left[\frac{\partial f(x,y,z,t)}{\partial z^n}\right] = r^n \bar{\bar{\bar{f}}}(p,q,r,s) - r^{n-1}\bar{\bar{\bar{f}}}(p,q,0,s)\cdots - r\frac{\partial^{n-2}\bar{\bar{\bar{f}}}(p,q,0,s)}{\partial z^{n-2}} - \frac{\partial^{n-1}\bar{\bar{\bar{f}}}(p,q,0,s)}{\partial z^{n-1}}. \quad (29)$$

The number of bars over a function serves to indicate the number of transformations involved: this number equals the number of complex variables appearing in the argument of the function. Since it is cumbersome to place several bars over each term, an alternate notation is to replace the total number of bars by conjunction of a numerically equal subscript and a single bar. In this notation (29) becomes

$$M\left[\frac{\partial^n f(x,y,z,t)}{\partial z^n}\right] = r^n \bar{f}_4(p,q,r,s) - r^{n-1}\bar{f}_3(p,q,0,s)\cdots - r\frac{\partial^{n-2}\bar{f}_3(p,q,0,s)}{\partial z^{n-2}} - \frac{\partial^{n-1}\bar{f}_3(p,q,0,s)}{\partial z^{n-1}}. \quad (30)$$

This symbolism, properly interpreted, is very convenient in determining the multiple transform of an unmixed derivative. Typically, a term such as $\frac{\partial^4 \bar{f}_3(p,q,0,s)}{\partial z^4}$ indicates: the fourth derivative of $f(x,y,z,t)$ with respect to z, evaluated at $z=0$ and triply transformed with respect to the variables x, y, and t, yielding—finally—a function of the three corresponding complex variables p, q, and s.

In a similar manner the multiple transform of a mixed partial derivative can be deduced from single Laplace theorems. Consider determination of $M\left[\frac{\partial^2 f(x,t)}{\partial x \partial t}\right]$ defined by

$$M\left[\frac{\partial^2 f(x,t)}{\partial x \partial t}\right] = \int_0^\infty e^{-pz} \int_0^\infty e^{-st} \frac{\partial^2 f(x,t)}{\partial x \partial t}\, dt\, dx$$

$$= \int_0^\infty e^{-pz} \frac{\partial}{\partial x} \int_0^\infty e^{-st} \frac{\partial f(x,t)}{\partial t}\, dt\, dx. \quad (31)$$

From (8)

$$\int_0^\infty e^{-st} \frac{\partial f(x,t)}{\partial t}\, dt = L_t\left[\frac{\partial f(x,t)}{\partial t}\right] = s\bar{f}(x,s) - f(x,0). \quad (32)$$

Substituting (32) in (31) yields

$$M\left[\frac{\partial^2 f(x,t)}{\partial x \partial t}\right] = \int_0^\infty e^{-pz} \frac{\partial}{\partial x} [s\bar{f}(x,s) - f(x,0)]dx$$

$$= L_z\left[s \frac{\partial \bar{f}(x,s)}{\partial x} - \frac{\partial f(x,0)}{\partial x}\right]. \quad (33)$$

Application of (8) to (33) yields the multiple transform of the mixed partial derivative

$$M\left[\frac{\partial^2 f(x,t)}{\partial x \partial t}\right] = sp\bar{\bar{f}}(p,s) - s\bar{f}(0,s) - p\bar{f}(p,0) + f(0,0). \quad (34)$$

Equation 34 can be confirmed by direct integration of the defining integral (31). The multiple transforms of mixed partial derivatives of higher order can be obtained in a similar manner.

The prime purpose of this paper is to formulate the general procedure for solution of problems by multiple Laplace transforms. Specific determination and statement of conditions necessary to existence of the direct and inverse transforms of functions is outside the present scope. It is assumed that all functions treated satisfy these conditions and have multiple transforms, as is the case with most functions encountered in practice.

6. AN ILLUSTRATIVE PROBLEM FROM ELECTROSTATIC THEORY

It is desired to find the electrostatic potential $v(x,y)$ in the space bounded by the planes $x=0$, $x=\pi$, $y=0$, and $y=y_0$ when these planes are maintained at the potential indicated in Fig. 1. The solution $v(x,y)$ must satisfy Laplace's equation at all points in the encompassed space. Accordingly, the partial differential equation to be solved is

$$\frac{\partial^2 v(x,y)}{\partial x^2} + \frac{\partial^2 v(x,y)}{\partial y^2} = 0. \quad (35)$$

The boundary conditions to be satisfied are

$$\begin{aligned} v(0,y) &= 0, \\ \frac{\partial v}{\partial y}(x,0) &= 0, \\ v(\pi,y) &= 1, \\ v(x,y_0) &= 0. \end{aligned} \tag{36}$$

This problem has boundary conditions of the distributed type: that is, the function or its partial derivative is known along different lines of the boundary. The multiple Laplace solution follows.

Taking the multiple transform of each term of (35) by the use of (7) and (27) yields

$$p^2\bar{v}(p,q) - p\bar{v}(0,q) - \frac{\partial \bar{v}(0,q)}{\partial x} + q^2\bar{v}(p,q) - q\bar{v}(p,0) - \frac{\partial \bar{v}(p,0)}{\partial y} = 0. \tag{37}$$

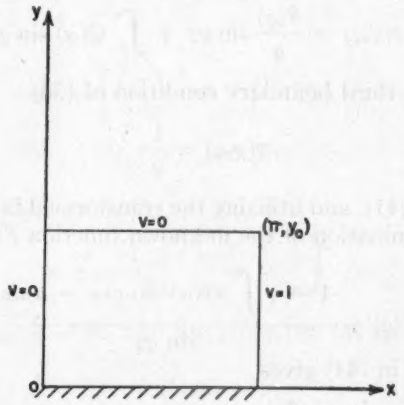

FIG. 1.

Transforming the first two boundary conditions of (36) gives

$$\begin{aligned} \bar{v}(0,q) &= 0 \\ \frac{\partial \bar{v}(p,0)}{\partial y} &= 0. \end{aligned} \tag{38}$$

These transformed boundary conditions are required in (37) and can be immediately substituted therein. $\frac{\partial \bar{v}(0,q)}{\partial x}$ and $\bar{v}(p,0)$ are also required in (37), but these are transforms of $\frac{\partial v(0,y)}{\partial x}$ and $v(x,0)$ which are not among the boundary conditions of the problem as given in (36). Hence

$\frac{\partial v(0,y)}{\partial x}$ and $v(x,0)$ are taken to be the unknown functions $F(y)$ and $G(x)$. These transform into the unknown functions $\bar{F}(q)$ and $\bar{G}(p)$

$$\begin{aligned} \bar{F}(q) &= \frac{\partial \bar{v}}{\partial x}(0,q) \\ \bar{G}(p) &= \bar{v}(p,0). \end{aligned} \tag{39}$$

Substituting (38) and (39) in (37) and rearranging,

$$\bar{v}(p,q) = \frac{\bar{F}(q)}{p^2+q^2} + \frac{q\bar{G}(p)}{p^2+q^2}. \tag{40}$$

The inverse transform of (40) with respect to p (for this inversion, q is considered a constant parameter) can be obtained from any comprehensive table of single Laplace transforms. (Gardner and Barnes, 1946, transform pair numbers 9 and 1.201 (6)).

$$L^{-1}{}_p[\bar{v}(p,q)] = \bar{v}(x,q) = \frac{\bar{F}(q)}{q}\sin qx + \int_0^x G(\alpha)\sin q(x-\alpha)d\alpha. \tag{41}$$

Transforming the third boundary condition of (36)

$$\bar{v}(\pi,q) = \frac{1}{q}. \tag{42}$$

Letting $x = \pi$ in (41), and utilizing the transformed boundary condition (42) allows determination of the unknown function $\bar{F}(q)$

$$\bar{F}(q) = \frac{1 - q\int_0^\pi G(\alpha)\sin q(\pi-\alpha)d\alpha}{\sin q\pi}. \tag{43}$$

Substituting (43) in (41) gives

$$\bar{v}(x,q) = \frac{1}{q}\frac{\sin qx}{\sin q\pi} - \frac{\sin qx}{\sin q\pi}\int_0^\pi G(\alpha)\sin q(\pi-\alpha)d\alpha + \int_0^x G(\alpha)\sin q(x-\alpha)d\alpha. \tag{44}$$

By utilizing $\int_0^\pi Q(\alpha)d\alpha = \int_0^x Q(\alpha)d\alpha + \int_x^\pi Q(\alpha)d\alpha$ and trigonometric manipulation, Eq. 44 can be rewritten as

$$\bar{v}(x,q) = \frac{1}{\sin q\pi}\left[\frac{\sin qx}{q} + \sin q(x-\pi)\int_0^x G(\alpha)\sin q\alpha\, d\alpha + \sin qx\int_x^\pi G(\alpha)\sin q(\alpha-\pi)d\alpha\right]. \tag{45}$$

Since the inverse transform of (45) does not appear in single Laplace transform tables, this inversion must be effected by actual evaluation

of the inverse integral. Accordingly,

$$v(x,y) = \frac{1}{2\pi i}\int_{Br.} e^{yq}\,\bar{v}(x,q)dq, \tag{46}$$

where $\bar{v}(x,q)$ is given by (45). The poles of $e^{qy}\,\bar{v}(x,q)$ are simple, occurring at $q = 0$ and $q = \pm n$. Accordingly, Cauchy's residue theorem can be applied

$$v(x,y) = \sum_{\text{Residues}} e^{yq}\,\bar{v}(x,q). \tag{47}$$

The residue at $q = 0$ is

$$\frac{x}{\pi}. \tag{48}$$

The residue at $q = n$ is

$$\sum_{n=1}^{\infty} e^{ny}\sin nx\left[\frac{(-1)^n}{n\pi} + \frac{1}{\pi}\int_0^{\pi} G(\alpha)\sin n\alpha\, d\alpha\right]. \tag{49}$$

The residue at $q = -n$ is

$$\sum_{n=1}^{\infty} e^{-ny}\sin nx\left[\frac{(-1)^n}{n\pi} + \frac{1}{\pi}\int_0^{\pi} G(\alpha)\sin n\alpha\, d\alpha\right]. \tag{50}$$

Summing residues from (48), (49), and (50) gives

$$v(x,y) = \frac{x}{\pi} + \sum_{n=1}^{\infty} 2\sin nx \times \cosh ny\left[\frac{(-1)^n}{n\pi} + \frac{1}{\pi}\int_0^{\pi} G(\alpha)\sin n\alpha\, d\alpha\right]. \tag{51}$$

Evaluating (51) at $y = y_0$, and applying the fourth boundary condition of (36)

$$v(x,y_0) = 0 = \frac{x}{\pi} + \sum_{n=1}^{\infty} 2\sin nx \times \cosh ny_0\left[\frac{(-1)^n}{n\pi} + \frac{1}{\pi}\int_0^{\pi} G(\alpha)\sin n\alpha\, d\alpha\right]. \tag{52}$$

Since $\frac{x}{\pi}$ can be expanded in a sine series,

$$\frac{x}{\pi} = \sum_{n=1}^{\infty}\frac{2}{n\pi}(-1)^{n+1}\sin nx, \tag{53}$$

the integral containing the unknown function $G(\alpha)$ can now be eliminated

$$\frac{2}{n\pi}\frac{(-1)^n\sin nx}{\cosh ny_0} = 2\sin nx\left[\frac{(-1)^n}{n\pi} + \frac{1}{\pi}\int_0^{\pi} G(\alpha)\sin n\alpha\, d\alpha\right]. \tag{54}$$

Substituting (54) in (51) yields the solution

$$v(x,y) = \frac{x}{\pi} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^n \sin nx \cosh ny}{n \cosh ny_0}. \tag{55}$$

This solution is in agreement with that obtained in Churchill (7, p. 288) where the problem is suggested as an exercise in Fourier transform theory.

7. AN ILLUSTRATIVE PROBLEM FROM THE THEORY OF HEAT

It is desired to find the temperature distribution $u(x,y,t)$ for the semi-infinite slab of Fig. 2 when the sides of the slab are maintained at the temperatures indicated, the initial temperature distribution at all points in the slab being zero.

The solution $u(x,y,t)$ must satisfy the heat equation at all points in the slab. Accordingly, the partial differential equation is

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = \frac{\partial u}{\partial t}. \tag{56}$$

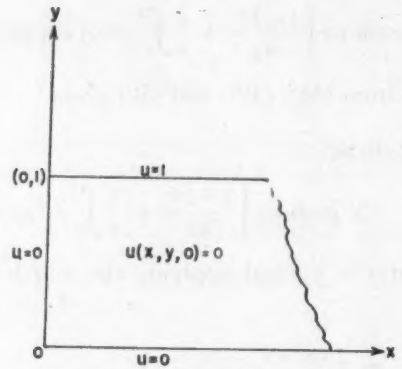

FIG. 2.

The stated boundary conditions are

$$\begin{aligned} u(x,y,0) &= 0 \\ u(0,y,t) &= 0 \\ u(x,0,t) &= 0 \\ u(x,1,t) &= 1 \\ |u(x,y,t)| &< M. \end{aligned} \tag{57}$$

This problem, encompassing a partial differential equation in three independent variables, has been solved by Jaeger (4) and Churchill (7, p. 210), utilizing single Laplace transformations in different methods. The multiple Laplace solution is now illustrated.

Taking the multiple transform of each term of (56) and rearranging

$$\bar{\bar{u}}(p,q,s) = \frac{p\bar{u}(0,q,s) + \frac{\partial \bar{u}}{\partial x}(0,q,s) + q\bar{u}(p,0,s) + \frac{\partial \bar{u}}{\partial y}(p,0,s) - \bar{u}(p,q,0)}{p^2+q^2-s}. \quad (58)$$

Taking the multiple transform of the first three boundary conditions of (57)

$$\begin{aligned} \bar{u}(p,q,0) &= 0 \\ \bar{u}(0,q,s) &= 0 \\ \bar{u}(p,0,s) &= 0. \end{aligned} \quad (59)$$

Since $\frac{\partial u(0,y,t)}{\partial x}$ and $\frac{\partial u(x,0,t)}{\partial y}$ are not given as boundary conditions of the problem, they are assumed as unknown functions $G(y, t)$ and $F(x, t)$, with transforms $\bar{G}(q,s)$ and $\bar{F}(p,s)$, thus

$$\begin{aligned} \bar{G}(q,s) &= \frac{\partial \bar{u}}{\partial x}(0,q,s) \\ \bar{F}(p,s) &= \frac{\partial \bar{u}}{\partial y}(p,0,s). \end{aligned} \quad (60)$$

Substituting (59) and (60) in (58) and letting $h^2 = p^2 - s$,

$$\bar{\bar{u}}(p,q,s) = \frac{\bar{G}(q,s)}{q^2+h^2} + \frac{\bar{F}(p,s)}{q^2+h^2}. \quad (61)$$

The inversion of (61) with respect to q (p and s are considered parameters for this inversion) can be obtained in single Laplace transform tables, (6, transform pair Nos. 9 and 1.201).

$$L^{-1}_q[\bar{\bar{u}}(p,q,s)] = \bar{u}(p,y,s) = \frac{\bar{F}(p,s)}{h}\sin hy + \frac{1}{h}\int_0^y \bar{G}(\alpha,s)\sin h(y-\alpha)d\alpha. \quad (62)$$

Transforming the fourth boundary condition of (57)

$$\bar{u}(p,1,s) = \frac{1}{ps}. \quad (63)$$

Evaluating (62) at $y = 1$ and applying the transformed boundary condition (62) allows determination of the unknown function $\bar{F}(p,s)$

$$\bar{F}(p,s) = \frac{h}{\sin h}\left[\frac{1}{ps} - \frac{1}{h}\int_0^1 \bar{G}(\alpha,s)\sin h(1-\alpha)d\alpha\right]. \quad (64)$$

Substituting (64) in (62)

$$\bar{u}(p,y,s) = \frac{\sin hy}{ps \sin h} - \frac{\sin hy}{h \sin h}\int_0^1 \bar{G}(\alpha,s) \sin h(1-\alpha)d\alpha + \frac{1}{h}\int_0^y \bar{G}(\alpha,s) \sin h(y-\alpha)d\alpha. \quad (65)$$

Equation 65 can be written as

$$\bar{u}(p,y,s) = \frac{1}{\sin h}\left[\frac{\sin hy}{ps} + \frac{\sin h(y-1)}{h}\int_0^y \bar{G}(\alpha,s) \sin h\alpha\, d\alpha + \frac{\sin hy}{h}\int_y^1 \bar{G}(\alpha,s) \sin h(\alpha-1)d\alpha\right]. \quad (66)$$

Transforming the last boundary condition of (57) with respect to t,

$$|\bar{u}(x,y,s)| < M''. \quad (67)$$

The inverse transform of (66) with respect to p and s, subject to condition (67) is obtained from Churchill (8, p. 211–213)

$$u(x,y,t) = y + \frac{2}{\pi}\sum_1^\infty \frac{(-1)^n}{n} \sin n\pi y \times \left\{e^{-n^2\pi^2 t} + \frac{1}{2}\left[e^{n\pi x}\, erfc\left(\frac{x}{2\sqrt{t}} + n\pi\sqrt{t}\right) + e^{-n\pi x}\, erfc\left(\frac{x}{2\sqrt{t}} - n\pi\sqrt{t}\right)\right] - e^{-n^2\pi^2 t}\, erfc\left(\frac{x}{2\sqrt{t}}\right)\right\}. \quad (68)$$

CONCLUSION

A general technique for solving boundary value problems utilizing the theory introduced in the first section of the paper is illustrated by the solution of two examples. The multiple transform of the solution of the boundary value problem is immediately obtained. In the absence of multiple transform tables the desired multiple inversion is effected by successive single inversions.

It is anticipated that as multiple transforms come into more common usage multiple transform tables will be compiled from combinations of presently known single transforms, and by direct evaluation of multiple complex integrals. With such tables available, the multiple Laplace solution of boundary value problems described by partial differential equations is as routine as the single Laplace solution of boundary value problems characterized by ordinary differential equations, as evidenced in the recent book on double transforms by Voelker and Doetsch (9.)

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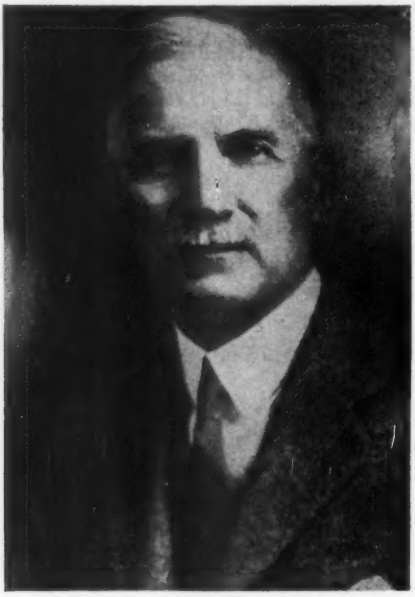
(9) D. VOELKER AND G. DOETSCH, "Die zweidimensionale Laplace-Transformation. Eine Einführung in ihre Anwendung zur Lösung von Randwentproblemen nebst Tabellen von Korrespondenzen," Basel, Verlag Birkhäuser, 1950.

Loss of an Associate Editor.—John Zeleny, Associate Editor of the JOURNAL OF THE FRANKLIN INSTITUTE and outstanding teacher of physics, died at his home in New Haven, Conn., on June 19, 1951, aged 79.

Born in Racine, Wisconsin on March 26, 1872, he was the son of Anthony Herbert and Josephine Pitka Zeleny. He received his B.S. degree from the University of Minnesota in 1892 and his Ph.D. degree in 1906. He also studied at the University of Berlin in 1897 and was awarded the bachelor's degree by Cambridge University in 1899.

He was an Instructor in Physics at the University of Minnesota from 1892 to 1896, Assistant Professor from 1896 to 1900, Associate Professor from 1900 to 1908, and Professor and head of the department from 1908 to 1915. He served as Acting Dean of the Minnesota Graduate School from 1912



JOHN ZELENY

to 1913. Dr. Zeleny was Professor, Chairman of the Department, and Director of Graduate Studies in Physics, at Yale University, from 1915 to 1940. Since 1940 he served as Professor-Emeritus.

In 1940 he received a signal honor when he was elected President of the American Physical Society. He was also a member of the American Philosophical Society, the American Association for the Advancement of Science, the American Academy of Arts and Sciences, the American Association of University Professors, the American Association of Physics Teachers, Phi Beta Kappa, and Sigma Xi. He wrote many monographs and articles for professional scientific journals, six of which were published in the JOURNAL OF THE FRANKLIN INSTITUTE during the period from 1930 to 1941.

Dr. Zeleny's death will be noted with regret by scientists the world over.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS *

PRECISE DETERMINATION OF MOISTURE IN RUBBER

An improved apparatus for precise determination of moisture in rubber has been developed by Max Tryon of the National Bureau of Standards. Possessing significant advantages over devices now available commercially, the new apparatus[1] should provide a rapid, simple means for accurate determination of water in leathers, textiles, oils, dried foods, and other organic materials. At the same time it offers a convenient tool for basic research in these fields.

The Bureau's apparatus is used in the method which involves the formation of a minimum-boiling azeotrope (constant-boiling mixture) of an immiscible organic liquid with the water present in the material, distillation of the azeotrope, and separation of the water as a separate phase for volumetric determination. Decomposition of the sample is prevented by the relatively low temperature at which the distillation takes place.

While several types of apparatus have been used previously to separate out and measure moisture in this way, most of these devices have disadvantages which limit their convenience and accuracy. For example, the water usually tends to adhere to parts of the apparatus rather than to collect in the graduated portion, where its volume is to be measured. Other problems have been the difficulty in reading accurately the volume of water collected and poor separation of the water from the organic liquid. In connection with a broad program at the Bureau on the chemical and physical properties of Government synthetic rubbers, it became necessary to determine the small amounts of water present in certain types of synthetic rubber which could not be analyzed by the usual procedures. The Bureau, therefore, developed the improved apparatus, which the Office of Rubber Reserve has now accepted as a referee method for determining moisture in all types of synthetic rubber.

This apparatus consists essentially of a distillation flask in which the sample is heated, a reflux condenser with a drip tip, a trap for collecting the water which separates out in the condenser, a capillary tube for measuring the distilled water, and a waste receiver with a drain stopcock at the bottom. The waste receiver is connected to a bottle of water, which is, in turn, connected by rubber tubing to a leveling bulb.

* Communicated by the Director.

[1] For further details, see "An Improved Apparatus for Determining Moisture in Rubber by Distillation with Toluene," by Max Tryon, *J. Research NBS*, Vol. 45, p. 362 (1950), RP 2146.

The sample is placed in the distilling flask along with sufficient dry toluene to completely cover it. Additional toluene is placed in the trap, and the flask is heated to distill the toluene-water azeotrope at a rapid rate. Droplets of distilled water appear in the condenser and settle to the bottom of the trap, the condensed toluene forming a separate liquid phase above the water. Distillation is stopped when no more water droplets appear in the distillate dropping into the trap. After the water in the trap has returned to room temperature, the leveling bulb is lowered until this water is drawn up into the calibrated capillary tube, where its volume can be measured. Lowering the leveling bulb still further flushes all of the water and toluene in the trap into the waste receiver, and the apparatus is ready for another determination. This procedure allows another sample to be run almost immediately.

The apparatus is cleaned periodically by pouring toluene into the trap through the condenser and lowering the leveling bulb to draw the solvent through the capillary into the bottom of the waste receiver and out through the stopcock in the receiver. To reduce the time spent in cleaning the distillation flask, disposable paper linings, dried in quantity by a distillation procedure similar to that applied to the sample, have been used at the Bureau.

By collecting the water in a large-volume trap, sharp separation of water and toluene, not always possible with narrow water-collecting tubes, is achieved. This feature, combined with the use of the graduated capillary for actual measurement of the water volume, results in greater over-all precision.

Increased precision and accuracy have also been obtained by the use of a water-repellent coating of silicone polymer on all the inner surfaces of the apparatus to prevent water droplets from adhering to the glass. This makes it possible to collect all the water in the graduated capillary for measurement. Use of the coating also reverses the usual water-glass meniscus, providing a mercury-type meniscus which is easily seen in the capillary.

The results obtained with this apparatus at the Bureau on samples containing about 1 per cent of water have been of the same order of accuracy as those obtainable with the Karl Fischer technique. The method has been evaluated in several experiments, designed for statistical analysis, in which the effects of a number of possible variables were studied. It was found that the procedure when applied to rubber is characterized by a standard deviation of 0.023 per cent. For accurate work allowance must be made for incomplete recovery of all the water in the sample. In the case of rubber, the recovery is about 96 per cent.

AUTOMATIC DEVICE COMPUTES TIMEPIECE CORRECTION

An automatic correction-computing chronograph recently developed by H. A. Bowman and F. E. Jones of the National Bureau of Standards makes possible large savings in the time required to test clocks, watches, chronometers, and other timepieces. A differential gear system is used to subtract indicated time from standard time, and the operator merely records the correction shown on the dials of a revolution counter. Thus the opportunity for human error is reduced to a minimum.

In precision tests on timepiece performance, the quantity most often determined is "correction," defined as the difference between true standard time and the time indicated by the device under test. After the correction has been found, it is used in other computations to provide information on performance characteristics. Thus, determinations of temperature and position effects, as well as magnetic and isochronal characteristics, all depend basically upon the accuracy with which correction is obtained.

While several instruments for the rapid determination of rate are commercially available, these devices are not designed for precise evaluation of timepiece performance. In the past, accurate determination of correction has been accomplished by the use of a recording chronograph adjusted to standard time. The true standard time corresponding to any indicated time of observation was obtained by measuring distance along the chronograph sheet with a special scale. Numerous small time-consuming operations were involved, such as insertion of the record sheet in the chronograph, adjusting the chronograph with standard time, reading the standard time of observation from the chronograph sheet, recording this reading, and subtracting the indicated time of observation from the standard time. As a result, where large numbers of watches were under test simultaneously, an excessive amount of time was spent in determination of correction. The Bureau therefore undertook to develop an automatic instrument which would eliminate the waste of time and opportunity for error inherent in the older method.

In the Bureau's device, standard time is introduced into one of the wheels of the differential gear by a 60-rpm. synchronous motor operated on a quartz crystal-controlled frequency accurate to one part in 50 million. The time indicated by the watch under test is introduced into the second wheel of the differential gear, causing the differential shaft to take a position which is a function of the difference between indicated time and standard time. Thus a revolution counter operated by the differential shaft indicates correction.

Actually, the gear wheel through which indicated time is introduced is not rotated continuously since it is not ordinarily feasible to connect mechanically the watch under test with the differential gear system. Instead, the wheel is rotated manually through a given number of

revolutions which are indicated on a dial calibrated in minutes and seconds. The wheel is then clamped, and correction is read from the revolution counter at the instant the test watch shows this predetermined time.

In order to read the rapidly moving revolution counter, the observer stops the counter by depressing a telegraph key at the instant the watch is seen to have the desired reading. To avoid loss of time in the standard gear wheel, a memory device is provided which "remembers" how long the operator has the differential gear shaft clamped. This device takes the form of a second differential gear which absorbs and stores the motion of the synchronous motor on a slowly moving memory wheel. When the operator has finished recording the reading of the revolution counter, the memory wheel is returned to its initial position. In resetting the memory wheel, a number of rotations proportional to the time previously lost is automatically cranked into the revolution counter. The telegraph key, controlling a relay and solenoid, is used to clamp the differential gear shaft and at the same time to release the second differential system which actuates the memory wheel.

CONTROLLED HUMIDITY FOR RESEARCH

Convenient means of producing and maintaining atmospheres of known relative humidity at any of the temperatures encountered in a radiosonde flight has been developed at the National Bureau of Standards. A recirculating type of apparatus was devised for calibration and research purposes by A. Wexler and associates of the Bureau's mechanical instrument laboratory under the sponsorship of the Bureau of Ships, Department of the Navy.

The need for such a device results from the use of the electric hygrometer for sensing water vapor content of the air during a meteorological sounding of the upper atmosphere by means of the radiosonde. During a flight, the hygrometer may be subjected to a wide range of temperatures and humidities, as well as air flows, corresponding to balloon ascent rates of 1000 ft. per minute or more. The new equipment was designed primarily for operation at temperatures above freezing, but is equally useful at temperatures down to $-40°$ C. Provision was made for obtaining discrete changes in humidity and temperature and for maintaining given air speeds up to 1500 ft. per minute. The recirculating apparatus supplements equipment previously developed at the Bureau for use at temperatures below freezing.

A known relative humidity is produced by saturating a stream of air with water vapor at a given temperature and then raising the temperature of the air to a specified higher value. The relative humidity, at the higher temperature, is the ratio of the saturation

pressure of water vapor at the lower temperature to the saturation pressure of water vapor at the elevated temperature. A gas pump circulates air from a saturator into a test-chamber and then back into the saturator. Complete saturation is achieved, simply and efficiently, by recirculating the air over water or ice in the saturator, in a closed system.

The temperature of the saturator is maintained constant by a thermostatted liquid bath while that of the test-chamber is controlled by means of a heater in the air stream. This is possible because the air from the saturator must necessarily be brought to a higher temperature and hence the only requirement for achieving any desired test-chamber temperature is the introduction of the requisite amount of heat into the air stream.

The important features of the saturator are its simplicity of design, its adaptability for temperatures below as well as above the freezing point of water, and its effective saturation at both high and low flows. These are achieved in large measure by imparting a centrifugal action to the entrant air stream. The saturator is a cylindrical chamber containing distilled water to a convenient depth. Air is discharged through a nozzle into the chamber above the water surface and tangential to the vertical walls and then exhausted through a central port in the top. The centrifugal action creates a whirlpool which greatly increases the liquid surface and thoroughly mixes water vapor with the air. Spray and liquid droplets are forced to the walls by centrifugal force which results in little tendency for liquid water to emerge through the exit port except at low flows. Under these conditions, a multilayer fine wire screen baffle at the exit traps and prevents water from passing out of the saturator. Since air does not bubble through water but only passes over its exposed surface, the water may be frozen without impairing the functioning of the saturator.

Rapid and discrete changes in relative humidity are achieved by utilizing four independent but identical recirculating systems arranged so that their test chambers may be interchanged easily and quickly. Thus, if a different temperature is maintained in each of the four saturators, and if the same temperature is maintained in each test chamber, the relative humidity in each test chamber is different. By interchanging the test chambers, the relative humidities therein undergo discrete changes as each test chamber communicates with a different saturator.

The interchange of test chambers is effected by a pneumatic switch consisting of two ground and lapped plates to which are attached air lines leading from the saturators to the test chambers. A quarter turn of the top plate with respect to the bottom plate advances each test chamber to a new position and connects each test chamber with a different saturator. The relative humidity can be changed at a

speed of about 1 to 2 seconds and depends primarily on the speed with which the switch can be rotated.

The gravimetric method of moisture determination was employed to check the accuracy of the apparatus. Measurements of the relative humidity produced in the test chamber were made over a wide range of test chamber temperatures, relative humidities, and air flows. The results reveal an average difference in percentage of relative humidity of ± 1.2 per cent between the relative humidity measured by the two techniques. As an additional check, a thermocouple psychrometer was employed to measure the actual relative humidity in the test chamber. These results show an average difference of ± 0.9 per cent between the psychrometric and the apparatus relative humidity measurements.

NOTE: For further details, see "Recirculating Apparatus for Testing Hygrometers," by Arnold Wexler, *J. Res. NBS*, Vol. 45, No. 5, p. 357, 1950 (RP 2154); and Divided Flow, Low Temperature Humidity Test Apparatus," by Arnold Wexler, *J. Res. NBS*, Vol. 40, No. 6, p. 479, 1948 (RP 1897).

THE FRANKLIN INSTITUTE

THE WRIGHT BROTHERS' AERONAUTICAL ENGINEERING COLLECTION AT THE FRANKLIN INSTITUTE, PHILADELPHIA, PA.*

BY

RALPH H. McCLARREN [1]

Dr. Orville Wright deeded to The Franklin Institute in his will and through the Executors of his Estate all of his and his brother's, Wilbur Wright's, original wind tunnel apparatus, model airfoils, test data and drawings of their early airplanes. The collection also includes airfoil models tested at McCook Field during 1919, 1920, and 1921 as well as some of Orville Wright's experimental aviation devices with which he worked during his lifetime. These include a shaper and cutters to prepare wax airfoil models, a special scale, smoke apparatus for wind tunnel use, a bank indicator, an incidence indicator, automatic control devices for wind tunnel and airplane control, an automatic landing device and a cypher machine.

Among the original drawings the collection includes those of the first successful airplane—the 1903 biplane, and the 1904, 1905, 1907, and 1910 biplanes. Engine drawings include the 1910 motor and prints of the 1903 motor.

In addition to the intrinsic and irreplaceable value of the many items in the collection there exists within them a record of the logical, step-by-step program of engineering research and development by which the Wright Brothers enabled themselves to achieve success in flying their first powered airplane. Therein lies a record of their systematic wind tunnel tests conducted to give them reliable lift, drag and L/D values to enable them to engineer the design of the first successful airplane. Test results were collaborated by building and test-flying gliders to determine the scale effects from wind tunnel data to full scale wings. It is no little wonder that by such scientific methods two men, then known better for their printing, publishing and bicycle activities, were first to conquer the art of flight with a heavier than air machine.

Figure 1 shows the original lift balances made in 1901. Figure 2 is the drag (drift) measuring balance. It is incomplete; one additional piece has lately been found and added to it. The wind tunnel models, airfoils (aerofoils) used in the December 1901 wind tunnel experiments are shown in Fig. 3. Figure 4 is a photograph of a replica of the 1901 wind tunnel. It is currently

* Reference is noted to "The Papers of Wilbur and Orville Wright," by M. W. McFarland and A. G. Ranstrom in the *Library of Congress Quarterly Journal of Current Acquisitions*, Vol. 7, No. 4, August 1950. In addition to the materials relating to the Wright Brothers deposited with the Library of Congress and The Franklin Institute, the following institutions received bequests through the executors of the estate: Dayton Art Institute, Institute of Aeronautical Sciences, Educational & Musical Arts, Inc., Dayton Public Library, Wright Library, Dayton, Oberlin College, Miami University, Dayton Engineers' Club and the Smithsonian Institution. Refer to p. 33 of the article cited.

[1] Assistant to Executive Vice-President, The Franklin Institute, Philadelphia, Pa.

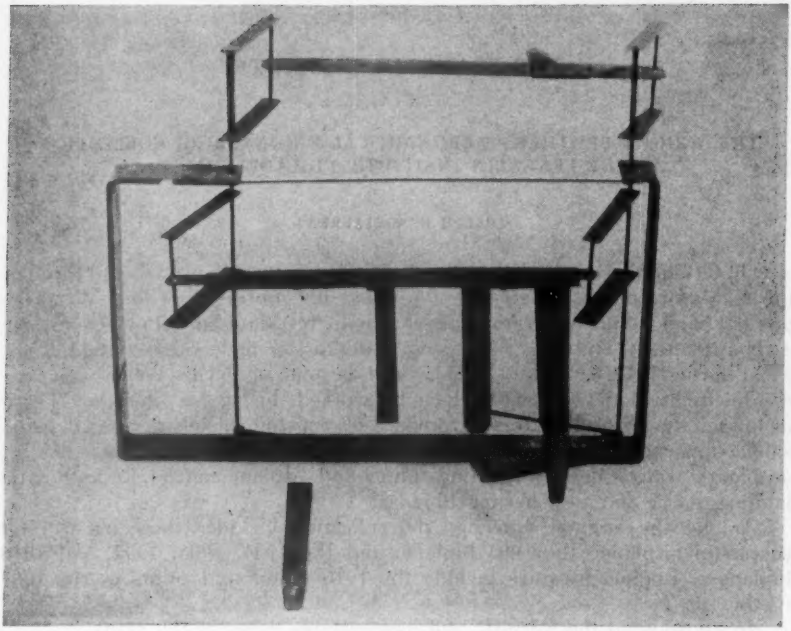


FIG. 1. 1901 lift balance.

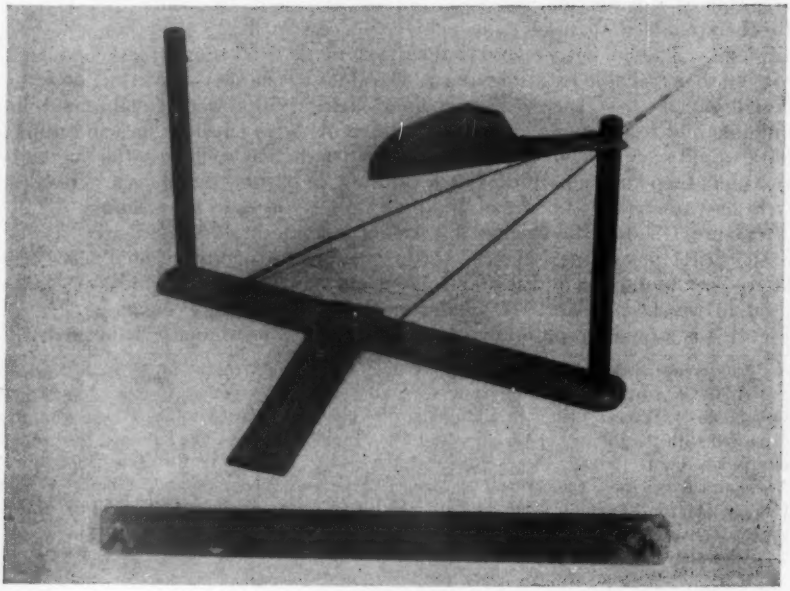


FIG. 2. 1901 drag (drift) balance.

on exhibit in The Institute's Hall of Aviation. A reproduction of the original graph showing lift values for various angles of attack appears in Fig. 5. Lift values for 1901 models Nos. 4, 5, 6, 7, 8 and 9 are plotted.

Figures 6 to 21 illustrate some of the other models included in the collection. There follows a complete listing of all the items:

WRIGHT'S 1901 WIND TUNNEL APPARATUS

48–44–1† *Lift Balance*—Original 1901—Wright Brothers used it to make measurements of lift on various wing models (aerofoils). Made of steel and hack-saw blades. Over-all size 12″ × 10″ × 6″.

NOTE: Original balances were misplaced when moved to 15 N. Broadway, Dec. 6, 1916. Were found in attic, 15 N. Broadway, Dec. 9, 1946.

48–44–2 *Drag (Drift) Balance*—Original 1901—Used by the Wrights to make measurements of drag on various wing models (aerofoils). Made of steel and hacksaw blades. Over-all size 12″ × 16″ × 7″.

48–44–3 *Airfoils (Aerofoils)*—Thirty-eight original models used by the Wrights in December 1901 Wind Tunnel Investigation.

No. 1—Plane, Aspect 1, Span 2.47″, Chord 2.43″, Area 6 sq. in.
No. 2—Plane, Aspect 4, Span 4.82″, Chord 1.24″, Area 6 sq. in.
No. 3—Plane, Aspect 6, Span 6.0″, Chord 1.0″, Area 6 sq. in.
No. 4—Arc, Camber 1/12 Chord, Span 2.5″, Chord 2.4″, Area 6 sq. in.
No. 5—Arc, Camber 1/16 Chord, Span 2.5″, Chord 2.4″, Area 6 sq. in.
No. 6—Arc, Camber 1/16 Chord, Span 2.5″, Chord 2.4″, Area 6 sq. in.
No. 7—Arc, Camber 1/12 Chord, Span 6.0″, Chord 1.0″, Area 6 sq. in.
No. 8—Arc, Camber 1/16 Chord, Span 6.0″, Chord 1.0″, Area 6 sq. in.
No. 9—Arc, Camber 1/20 Chord, Span 6.0″, Chord 1.0″, Area 6 sq. in.
No. 10—Parabolic, Camber 1/12 Chord, Span 6.0″, Chord 1.0″, Area 6 sq. in.
No. 11—Parabolic, Camber 1/16 Chord, Span 6.0″, Chord 1.0″, Area 6 sq. in.
No. 12—Parabolic, Camber 1/20 Chord, Span 6.0″, Chord 1.0″, Area 6 sq. in.
No. 15—Parabolic, Camber 1/12 Chord, Span 2.5″, Chord 2.4″, Area 6 sq. in.
No. 16—Parabolic, Camber 1/16 Chord, Span 2.5″, Chord 2.4″, Area 6 sq. in.
No. 17—Parabolic, Camber 1/20 Chord, Span 2.5″, Chord 2.4″, Area 6 sq. in.
No. 18—Arc, Camber 1/20 Chord, Span 4.84″, Chord 1.23″, Area 6 sq. in.
No. 19—Parabolic, Camber 1/20 Chord, Span 4.84″, Chord 1.23″, Area 6 sq. in.
No. 20—Bird Segment, Span 6.5″, Max. Chord 1.39″, Area 6 sq. in.
No. 21—Parabolic Segment, Camber 1/20 Chord, Span 6.5″, Max. Chord 1.39″, Area 6 sq. in.
No. 22—Parabolic, Camber 1/20 Chord, Span 4.5″, Chord .66″, Area 3 sq. in.
No. 23—Parabolic, Camber 1/20 Chord, Span 4.5″, Chord .66″, Area 3 sq. in.
(No. 24)—Surfaces No. 22 and 23 Superposed, Total Area 6 sq. in.
No. 25—Tapered with rounded tips, Span 6″, Chord .74″, Area 4 sq. in.
No. 26—Parabolic, Camber 1/20 Chord, Span 4.5″, Chord .66″, Area 3 sq. in.
(No. 27)—Surfaces 22, 23, and 26 Superposed, Total Area 9 sq. in.
No. 30—Hook, Camber 1/5.75 Chord, Span 4.5″, Chord 1.09″, Area 5 sq. in.
No. 31—Parabolic, Camber 1/12 Chord, Span 7.25″, Chord 1.56″, Area 8 sq. in.
No. 32—Tapered, rounded tips, Span 6.0″, Chord .74″, Area 4 sq. in.
(No. 33)—Surfaces 25 and 32 Superposed, Area 8 sq. in., Gap .93 Chord.
No. 34—Arc, tapered, pointed tips, Span 7.12″, Chord 1.6″ max.
No. 35—Bird, underside Camber 1/10 Chord, Span 6″, Chord 1″, Area 6 sq. in.
(No. 40)—Surfaces 18 and 19 Superposed, Area 12 sq. in., Gap .535 Chord.
(No. 41)—Surfaces 18 and 19 Superposed, Area 12 sq. in., Gap .914 Chord.
(No. 42)—Surfaces 18 and 19 Superposed, Area 12 sq. in., Gap .4 Chord.
(No. 43)—Surfaces 18 and 19 Superposed, Area 12 sq. in., Gap .2 Chord.
(No. 44)—No notations regarding size, etc.
No. 45—Arc, Camber 1/12 Chord, Span 12.5″, Chord 1.25″, Area 15.62 sq. in.
(No. 46)—Camber 1/20 Chord, Span 12.5″, Chord 2.5″, Area 31.25 sq. in.
No. 48—Parabolic, 1/20 Chord, Span 6.25″, Chord 2.5″, Area 15.62 sq. in.
(No. ?)—Surface 48 and 48 Superposed, Total Area 31.25 sq. in., Gap .6 Chord.

NOTE: Thirty nine (39) data sheets of airfoil characteristics are included and correspond to Numbers noted above. The Numbers in ( ) indicate data sheets only. Included above are

† Items with reference number 48–44– are in the exhibit preparation storage room being prepared for exhibit in the Museum at some future time.

30 airfoils numbered as noted. It seems that no airfoils or records exist for the skipped No's. 13, 14, 28, 29, 36, 37, 38, 39 and 47. Possibly those models which have been arbitrarily numbered 50 to 57 inclusive are those noted in previous sentence.

No. 50—Arc, Camber ?, Span 4.5", Chord .66".
No. 51—Parabolic, Camber ?, Span 5.0", Chord 1.25".
No. 52—Arc, rounded tips, Camber ?, Span 6.0", Chord 1.0".
No. 53—Parabolic, Camber ?, Span 6.0", Chord 1.25".
No. 54—(Also marked No. 3 and No. 12)—Parabolic, Camber ?, Span 3", Chord 2.8".
No. 55—Parabolic, heavy leading edge, Span 9", Chord 1.5".
No. 56—Arc, turned-up trailing edge, Span 9", Chord 1.5".
No. 57—Parabolic, thick section, turned-up trailing edge, Span 9", Chord 1.5".

NOTE: Airfoils 50 to 57 are numbered arbitrarily. In notes available no data exist. Of special interest are Nos. 56 and 57 which have turned-up trailing edges.

DRAWINGS OF THE 1901 APPARATUS

629.133 Wr 15.11‡ *Drawing—Lift Balance of 1901, Wright Brothers.* Ink on white paper stock. This drawing is not dated, might have been made from old records or notes. Shows dimensions on plan and elevation views. Size 15" × 19½".

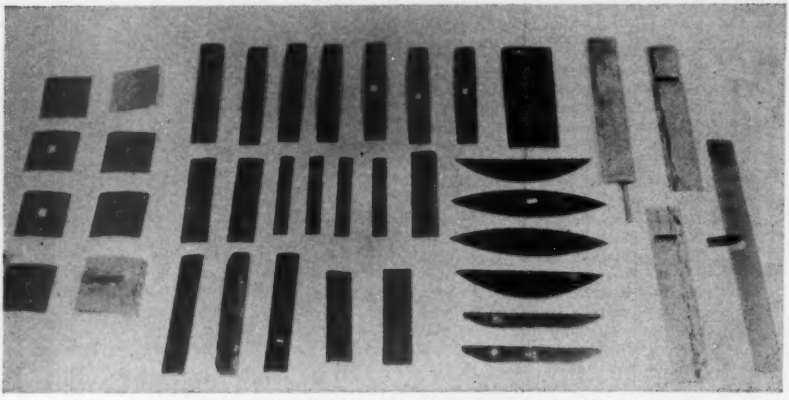


FIG. 3. 1901 wind tunnel model airfoils.

15.12 *Drawing—Resistance Surfaces for Wright Brothers 1901 Lift Balance.* Drawing is not dated, no dimensions, on same stock as 629.133 Wr 15.11. Size 15" × 9".

15.13 *Drawing—Drift (Drag) Balance of 1901, Wright Brothers.* Ink on white paper stock. This drawing is not dated. Dimensions are incomplete. Size 13" × 19".

15.14 *Drawing—Wind Tunnel of 1901—Wright Brothers.* Ink on white paper stock. Scale 1/8" = 1". Not dimensioned or dated. Size 17" × 8".

15.15 *Photostat of 629.133 Wr 15.14, 1901 Wind Tunnel.*

15.21 *Drawing—Models for Wind Tunnel.* Original plottings (made Dec. 1901) giving profile and plan form of the airfoils measured in the wind tunnel of 1901. Shown are models numbered 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 30, 31, 32 and 35. Notes indicate #24 = #22 and #23 superposed, #27 = #22 and #23 and #26 superposed, #33 = #5 and #32 superposed, #40 = #18 and #19 superposed 11/16" apart, #41 = #18 and #19 superposed 18/16" apart, #42 = #18 and

‡ All items with reference number 629.133 Wr—are presently deposited in the Library of The Franklin Institute.

#19 superposed 1/2" apart, #43 = #18 and #19 superposed 1/4" apart. Ink on tracing cloth. Size 20" × 24".

NOTE: "Superposed" is word used by the Wrights for biplane combination if two models were used and triplane if three were used.

DATA SHEETS AND NOTES OF THE 1901 WIND TUNNEL TESTS

629.133 Wr 15.31 *Graph. Lift vs. Angle of Attack.* 1901 Models Nos. 1, 2, and 3 and Duchemin model. Ink on cross section paper. Size 8½" × 14".

15.32 *Graph. Lift vs. Angle of Attack.* 1901 Models Nos. 4, 5, 6, 7, 8, and 9. Ink on cross section paper. Size 8½" × 14".

15.33 *Graph. Lift vs. Angle of Attack.* 1901 Models Nos. 10, 11, 12, 15, 16, and 17. Ink on cross section paper. Size 8½" × 14".

FIG. 4. Replica of 1901 wind tunnel.

15.34 *Graph. Lift and Drift vs. Angle of Attack.* 1901 Models Nos. 7, 8, and 9. Ink on tracing cloth. Size 10" × 12".

NOTE: Models 7, 8, and 9, size 1" × 6", are circular arc plates with systematically varied camber.

15.35 *Graph. Lift and Drift vs. Angle of Attack.* 1901 Models Nos. 10, 11, and 12. Ink on tracing cloth. Size 10" × 12".

NOTE: These sections had same amount of camber as Nos. 7, 8, and 9 but with maximum camber in a more forward location.

15.36 *Sheets—Four (4) Wind Tunnel Data from Wilbur Wright's 1901 Note Book.* Figures of angle of attack and instrument reading for airfoils of curved sections, some with upturned trailing edge. Size of sheets 8" × 19" for -1 and -2, size 8" × 10" for -3, and -4.

15.37 *Sheet. Wind Tunnel Data.* Data similar to that on 629.133 Wr 15.36–1. Size 6" × 9½".

15.38 *Table. Conversion from feet per second to miles per hour.*

15.39 *Wall Paper Notes. Diagrams of Angular Position of Wind Tunnel Balance during Tests.* Made in 1901 on Tests of Airfoils Nos. 1, 2 and 4. Total of 8 pieces size 4″ × 8″ and some 8″ × 8″. Three are dated September, 1901.

15.41 *Data Sheets. Four (4) Wind Tunnel Test Measurements Made March 24 and 25, 1902.* Model No. 9, new with uprights, superposed, new front edge, etc. Brown wrapping paper. Size 7″ × 10″.

15.42 *Data Sheets. Six (6) Miscellaneous Data Sheets on Strut Shapes, Lilienthal Wing, Air Screw, etc.* Sizes various from 3″ × 4″ to 4″ × 7″.

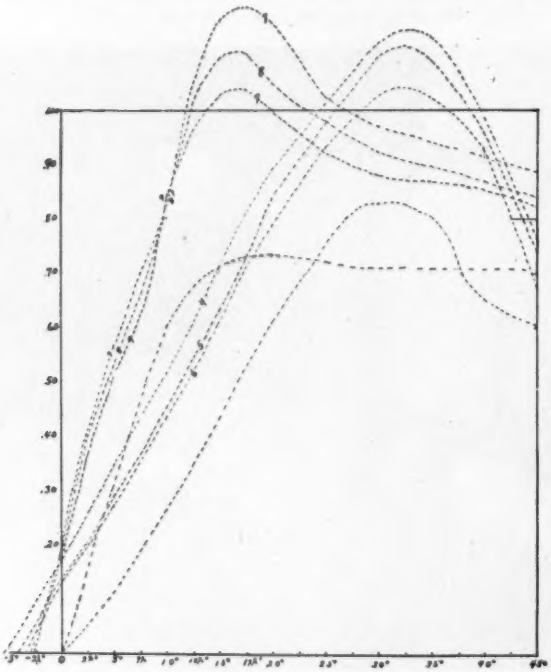


FIG. 5. Lift curves—1901 test data.

15.43 *Note Book. 1901 Wind Tunnel Measurements.* Airfoils #18, #19, #20, #21, #22, #23 & #22, #25, #26, #27, #30, #31, #32, #25 & #32, #35, #18 & #19, #4, #5, #6, #7, #8, #9, #10, #11, #12, #13, #15, #16, #17. Referenced as Tangentials. Size of book 7″ × 9″.

15.44 *Notes. Four (4) Sheets. Calculations of Lift, Drift, and Head Resistance on Glider.* Test evidently made in 1902 or 1903 at Kitty Hawk. Area of Wings given as 290 sq. ft. Table of tests made on July 30, August 6, August 15 and 16. Values are given for angle, velocity, and total pull. There are 10 paragraphs of comments; #10 reads: "The important conclusion to be drawn from the table is that the dynamic efficiency of the unloaded machine is greatest at the speed of 10 meters at which point it reaches 15 lbs. pull for 98 lbs. lifted. Of this amount one half or 7.5 lbs. should be assigned to drift and the other half (7.5 lbs.) to head resistance." Size of sheets 5″ × 8″. Writing appears to be that of Wilbur Wright.

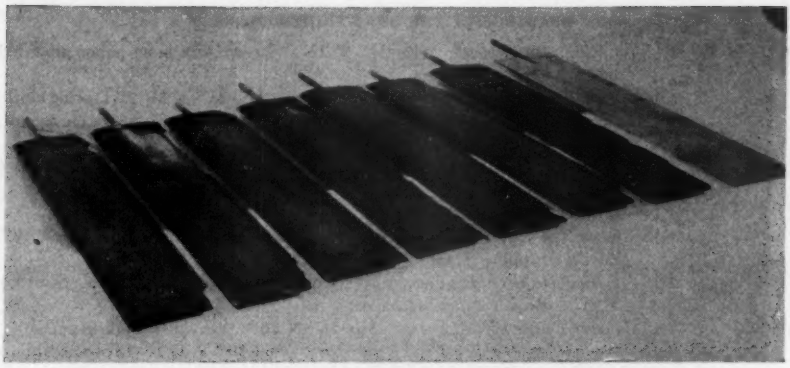


FIG. 6. Wax model airfoils used in 1919–1921 wind tunnel tests. R.A.F. 15–1, 15–2, 15–3, 15 × .8, 15 × 1.1, OW–1, R.A.F. 6, flat plate.

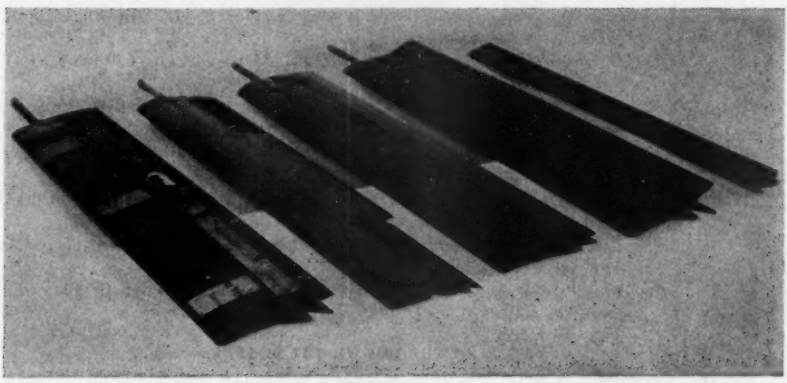


FIG. 7. High lift airfoils used in 1921–1922 wind tunnel tests.

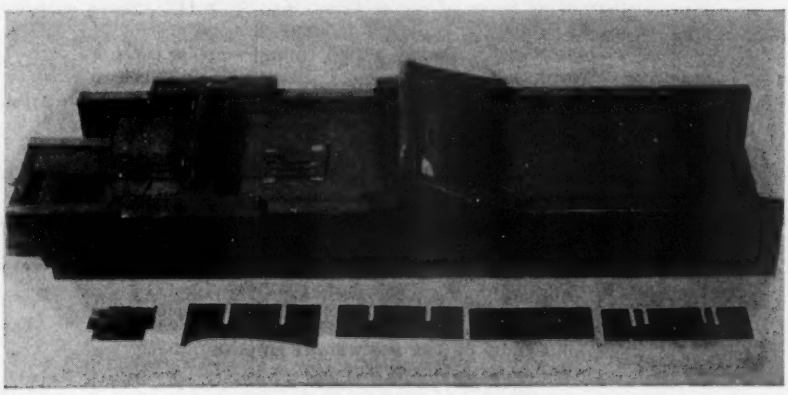


FIG. 8. Shaper for making wax model airfoils.

DRAWINGS OF THE 1903 WRIGHT BIPLANE

629.133 Wr 1.1 —*3 View (Incomplete)*. Size 24″ × 22″. Brown wrapping paper mounted on cardboard.

1.11—*Plan View of Wings and Front Elevation*. Size 25″ × 21″. Tracing cloth.

1.12—*Profile of 3 Ribs*. Full rib chord 6′–6½″, other ribs, one is at engine mount, one is center section rib. Size 6′–10″ × 23″. Brown wrapping paper.

1.13—*Elevator*. Rough layout, span 6′–0″, chord 20″. Size 36″ × 18″. Brown wrapping paper.

1.14—*Wing, Center Section*. Size 36″ × 16″. Brown wrapping paper.

1.15—*Right and Left Wing Tip Panels*. Cloth cover details. Size 33″ × 12″. Brown wrapping paper.

1.16—*Fitting Details*. Rudder, center section and rear strut hinge. Size 36″ × 10″. Brown wrapping paper.

1.17—*Lower Center Cloth Layout*. Size 18″ × 10″. Brown wrapping paper.

1.18—*Wing Hinges for Front and Rear Spars*. Size 10″ × 12″. Brown wrapping paper.

1.19—*Rear Spar Hinge for Top and Bottom Plane*. Size 9″ × 12″. Brown wrapping paper.

1.20—*Strut and Sross (Truss) Wire Fitting*. Size 11″ × 11″. Brown wrapping paper.

1.21—*Wright Biplane, Plan View of Wings*. Made from Tracing 629.133 Wr 1.11. Size 25″ × 21″.

1.22—*Wing Plan Views and Front Elevation*. Ink on white paper. Probably used for Tracing 629.133 Wr 1.11. Size 24″ × 19″.

1.23—*Front and Rear Elevation Views*. Size 24″ × 19″. Ink on white paper. (No date or other reference material.)

1.24—*Front and Rear Elevation Views*. Tracing. Probably made from 629.133 Wr 1.23. Size 25″ × 15″. (No date or other reference material.)

1.25—*Plan View, Upper and Lower Wing Panels*. Ink on white paper. (No date or reference notes.)

1.26—*Blue Print from NACA Drawing*. Made by J.B.R., March 10, 1928 from McF. Dwg M-3190.

DRAWINGS OF THE 1904 WRIGHT BIPLANE

629.133 Wr 2.11—*Center Section, Side Elevation*. Size 24″ × 11″. Brown wrapping paper.

2.12—*Center Section, Front Elevation*. Size 24″ × 10″. Brown wrapping paper.

2.13—*Outer Wing Section, Elevation View*. Size 20″ × 11″. Brown wrapping paper.

2.14—*Propeller Section*. Size 17″ × 10″. Brown wrapping paper.

NOTE: On back is drawing of layout of wing tip and elevator.

2.15—*No. 2 Horizontal Motor Cylinder*. Size 11″ × 8½″. Ink on white paper.

DRAWINGS OF THE 1905 WRIGHT BIPLANE

629.133 Wr 3.11—*Center Section, Side Elevation View*. Size 24″ × 17″. Brown wrapping paper.

3.12—*Center Section, Front Elevation View and Outer Wing Section*. Elevation view. Size 24″ × 18″. Brown wrapping paper.

3.13—*Engine—Cylinder and Connecting Rod*. Size 23″ × 15″. Brown heavy paper.

3.14 *Engine—End View*. Size 17″ × 24″. Brown wrapping paper.

DRAWINGS OF THE 1907 WRIGHT BIPLANE

629.133 Wr 4.11—*Wing Panels, Front Elevation View*. Size 29″ × 14″. Brown wrapping paper.

4.12—*Wing Panel Center Section, Front Elevation View.* Size 22″ × 15″. Brown wrapping paper.

4.13—*Drawing. Landing Skid Structure.* Size 23″ × 15″. Brown wrapping paper.

DRAWINGS OF THE 1909 WRIGHT BIPLANES

629.133 Wr 5.11 *U. S. Government Machine.* Front elevation view of center section and outer wing panels. Size 28″ × 12″. Brown wrapping paper.

5.12—*U. S. Government Machine.* Wing panels and landing skid, side elevation view. Size 23″ × 13″. Brown wrapping paper.

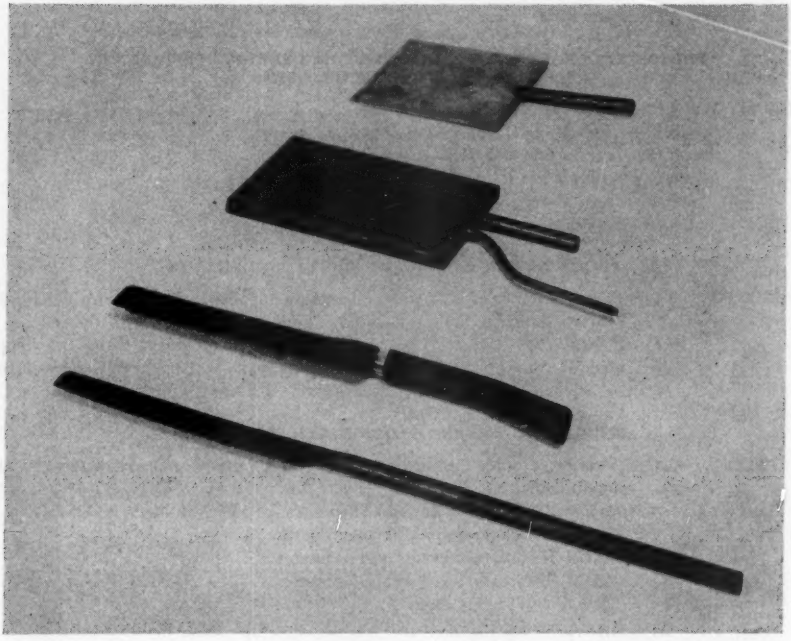


FIG. 9. Smoke apparatus and airfoils.

5.13—*U. S. Government Machine.* Chain guide. Size 28″ × 14″. Brown wrapping paper.

5.14—*Wright Aeroplane Built by Short Bros. Aeroplane Works.* Sectional elevation. Side view. Size 30″ × 20″. Blueprint.

5.15—*Wright Aeroplane Built by Short Bros. Aeroplane Works.* Plan view. Size 48″ × 30″. Blueprint.

DRAWINGS OF THE 1910 WRIGHT MOTOR, PROPELLER AND GERMAN DESIGNS

629.133 Wr 6.11—*Motor, End View.* Size 20″ × 25″. Ink on tracing cloth.

6.12—*Motor, End View.* Size 20″ × 25″. Blueprint of 629.133 Wr 6.11.

6.13—*Motor. Details of Cylinder, Connecting Rod, Piston, and Cam Shaft.* Size 36″ × 20″. Ink on tracing cloth.

6.14—*Motor, Details of Cylinder, Connecting Rod, Piston and Cam Shaft.* Size 36″ × 20″. Blueprint of 629.133 Wr 6.13.

6.15—*Motor Cam Shaft (for 8 Cylinder Belmonte Race Meet).* Size 30″ × 7″. Ink on tracing cloth.
6.16—*Propeller Section.* Construction plan. Size 19″ × 11″. Ink on tracing cloth.
6.17—*Propeller.* Plan, elevation and section views. Size 30″ × 20″. Ink on tracing cloth.
6.18—*Propeller for French Machine.* Plan, elevation and section views. Size 25″ × 20″. White paper.
6.19—*Package Containing German Drawings of the Wright Aeroplane.*

BLUEPRINT OF THE 1911 WRIGHT MODEL B

629.133 Wr 7.11—*Plan View.* Size 40″ × 30″. Blueprint.

PHOTOSTATS OF 1902 WRIGHT GLIDER (FROM DRAWINGS PREPARED BY WRIGHT FIELD, DAYTON, OHIO)

629.133 Wr 8.11—*Top Wing Assembly and Details.*
8.12—*Lower Wing Assembly and Details.*
8.13—*Tail Surface and Skid.*
8.14—*Fitting Details.*
8.15—*Three View.*
8.16—*Rudder Assembly and Details.*

PRINTS OF THE 1903 WRIGHT ENGINE AND BIPLANE

629.133 Wr 9.11—*Prints—1903 Wright Engines.* 12 prints included. Prepared by The Ford Motor Company.
10.11—*Prints—1903 Wright Biplane.* Complete set of prints, from drawings made by the National Cash Register Company in 1947 from the drawings by Science Museum, South Kensington, England.

AIRFOIL (AEROFOIL) INFORMATION AND SPECIFICATIONS

629.133 Wr 13.11—A series of notes on airfoil ordinates and aerodynamic characteristics as noted below:
Dayton Wright No. 8 Airfoil—Ordinates for 15″ Airfoil.
NACA 81—characteristics and ordinates.
NACA 58—characteristics and ordinates.
NACA 73—characteristics and ordinates.
Clark Y—MIT test data.
Specifications (ordinates for) W.A.L. #1, #17, #18, #21, #22, #23, #24, #25, #32, #33, #34, #35, #36 (Note on this "made Oct. 12, 1921"); R.A.F. #6, R.A.F. #15, #15 × 1.1, #15—.8, Albatross, Sloane, Martin II, O.W. #1—R.A.F. 6, U.S.A. #1, #27, Clark "A," "B," Prandtl #223, #225, #227, #242, #244, Dayton Wright #9, Gottingen #387, Dayton Wright T–1 #1 Section (May 25, 1922), Dayton Wright T–1 #5 Section.
Ordinates for Martin Airfoils M–I, M–II, M–III, M–IV.
Characteristics for: #223, USA #26, #225, #227, #224, #244, and #242.

WIND TUNNEL AIRFOIL MODELS USED IN 1919, 1920, AND 1921 TESTS

48–44–4 W.A.L.— 1 *Wax Model.* Span 18″, Chord 3″, Thin section, flat lower surface.
W.A.L.—18 *Wax Model.* Symmetrical Section.
W.A.L.—21 *Wax Model.* Span 18″, Chord 3″, Symmetrical Section.
W.A.L.—22 *Wax Model.* Span 18″, Chord 3″, Thick Section.
W.A.L.—22 *Wax Model.* Span 18″, Chord 3″, Symmetrical Section using upper template (22) for both surfaces. (This model is also marked 32.)

W.A.L.—23 *Wax Model.* Span 18″, Chord 3″, Thick Section.
W.A.L.—23 *Wax Model.* Span 18″, Chord 3″, Symmetrical Section using upper template (23) for both surfaces.
W.A.L.—24 *Wax Model.* Span 18″, Chord 3″, Medium Section.
W.A.L.—24 *Plaster Model.* Span 18″, Chord 3″, Symmetrical Section using upper template (24) for both surfaces. (This model is also marked 34.)
W.A.L.—25 *Wax Model.* Span 18″, Chord 3″, Medium Section.
W.A.L.—25 *Wax Model.* Span 18″, Chord 3″, Symmetrical Section using upper template (25) for both surfaces, also marked No. (39).
W.A.L.—36 *Wood Model.* Span 18″, Chord 4″, Symmetrical Section.
F.P. (5) *Five Flat Plates.* Span 18″, Chord 3″.
R.A.F. 15—1 *Wax on Metal Model.* Span 18″, Chord 3″.
R.A.F. 15—2 *Wax on Metal Model.* Span 18″, Chord 3″.
R.A.F. 15—3 *Wax on Metal Model.* Span 18″, Chord 3″.
R.A.F. 15 × .8 *Wax on Metal Model.* Span 18″, Chord 3″.

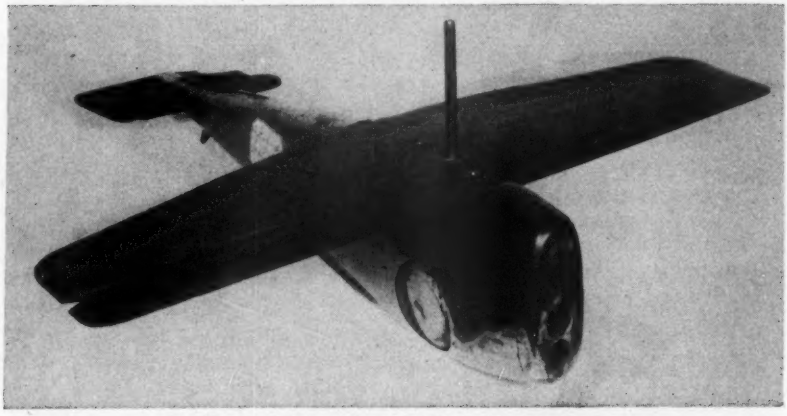


FIG. 10. Wind tunnel model of Gordon Bennett racer.

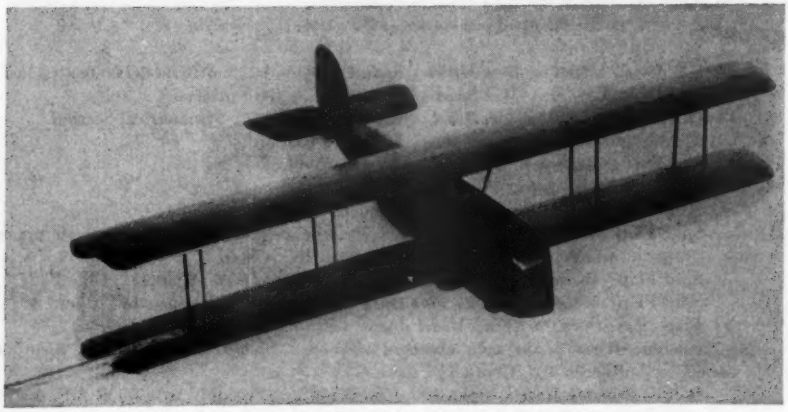


FIG. 11. Wind tunnel model of biplane with split flap.

R.A.F. 15 × 1.1 *Wax on Metal Model.* Span 18″, Chord 3″.
O.W. #1 (R.A.F. 6–1) *Wax on Metal Model.* Span 18″, Chord 3″.
R.A.F. 6 (–10–) *Wax on Metal Model.* Span 18″, Chord 3″.
U.S.A. 1–5 *Wax on Metal Model.* Span 18″, Chord 3″.
Albatross—1 *Wax on Metal Model.* Span 18″, Chord 3″.
Albatross—2 *Wax on Metal Model.* Span 18″, Chord 3″.
M II—#1 *Wax on Metal Model.* Span 18″, Chord 3″.
Prandtl (HLW) 242 *Wax on Wood Model.* Span 18″, Chord 3″.
Sloane *Wax on Wood Model.* Span 18″, Chord 3″.
U.S.A.—27 *Metal for Wax Model.* Span 18″, Chord 2¾″.
Prandtl (HLW) 223 *Metal for Wax Model.* Span 18″, Chord 2¾″.
Prandtl (HLW) 225 *Metal for Wax Model.* Span 18″, Chord 2¾″.
Prandtl (HLW) 227 *Metal for Wax Model.* Span 18″, Chord 2¾″.

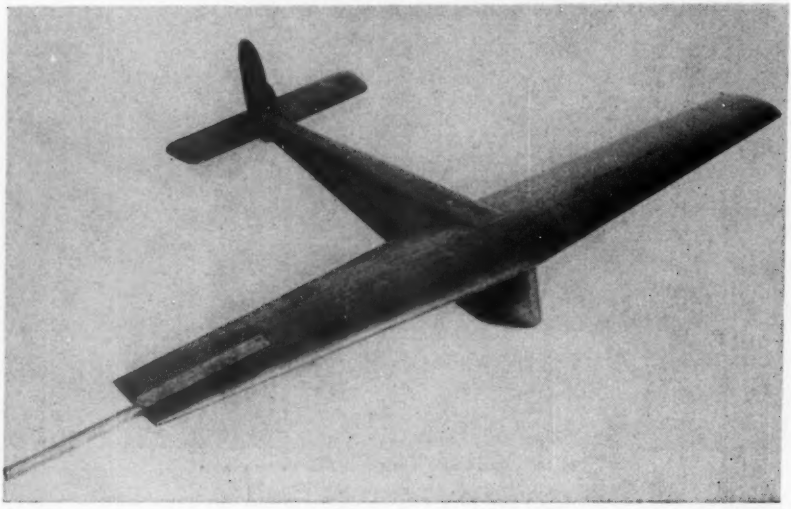


FIG. 12. Wind tunnel model of Dayton Wright monoplane.

U.S.A.—27 *Metal for Wax Model.* Span 18″, Chord 2¾″, with model body attached.
Metal Forms—Three (3). Span 18″, Chord 3″. (Not marked.)
D.W. U.S.A. Std. *Wood Model.* Span 18″, Chord 4″, Symmetrical Section.
Two Eiffel Sections *Wax on Metal.* Span 18″, Chord 4″.
R.A.F. 6–1 *Wax on Metal.* Span 12″, Chord 6″.
O.W. #x *Wood Model.* Span 18″, Chord 3″.
Patterns. Two (2) For Wax Metal Models, Span 18″, Chord 2¾″.
Split Flap *Wood Model with Hinged Trailing Edge Flap.* Holes through upper surface just aft of flap hinge. Span 18″, Chord 3″.
Split Flap *Wood Model with Hinged Trailing Edge Flap.* Span 18″, Chord 3″.
Split Flap *Wood Model with Flap Open to Fixed Position.* Span 18″, Chord 3″.
Flap *Less Open, for Wing Model Above.*
Aileron *Wood Model with Outboard Ailerons.* Span 18″, Chord 3″. Span of Aileron 4¾″, Chord 1¼″.
R.A.F. 6 *Metal Model.* Span 12″, Chord 5 1/16″. (Probably base for R.A.F. 6 wax model.)

Parabolic *Metal Model.* Sheet metal, Span 11¾", Chord 5¼".
Parabolic *Metal Model.* Sheet metal, Span 11¾", Chord 5¾".
Flat Plate *Metal.* Span 6", Chord 6".
Flat Plate *Metal.* Span 6", Chord 8½".
Flat Plate *Metal.* Span 7¼", Chord 7⅜" (marked 54.50 sq. in.)
Flat Plate *Metal.* 7⅜", Chord 7⅜".
Sections. Ten (10) small pieces of airfoil sections.

48–44–5 *Templates.* Twenty-eight (28), for making wax model airfoils. Chord 3". W.A.L. #1, #18, #20, #21, #22, #23, #24, #25, Prandtl (High Lift Wing) #223, #225, #227, #242, #244 (Made Oct. 1920), Clark #1, Sloane, R.A.F. 6, R.A.F. 15, R.A.F. 15 × .8, R.A.F. 15 × 1.1, Monoplane (Dayton Wright, Made Dec. 15, 1920), O.W. #1, M II (Martin), USA 1, USA 27, Albatross (Made in May 1920), Clark #2, Unmarked, and an R.A.F. 6 for 6" Chord.

48–44–6 *Shaper.* Used to cut wax airfoil model. Complete with two (2) cutting heads. Size: 40" long, 10" wide, 8" high. Weight: Approx. 200 lbs.

WIND TUNNEL TEST DATA AND NOTES

629.133 Wr 13.12 *R.A.F. #6 Test Results.* Folder containing data and curves regarding effect of speed on L/D, effect of aspect ratio on L/D. January 1920.

13.13 *Data and Curve.* Folder containing correction for Area of Model in Wind Tunnel. November 1920.

13.14 *Wind Tunnel Calibration.* Folder containing speed *vs.* water height and horsepower.

13.15 *Drawings of Molding Machine and Tunnel Instrument Made by Griffith Bacon in 1919.* Three drawings and a series of sketches.

13.16 *Wind Tunnel Measurements.* Folder of data, including information from MIT and McCook Field. Dates 1919 to 1922.

13.17 *Original Test Sheets.* Wind Tunnel Tests of various airfoils. Made 1919–20–21. Refer to 629.133 Wr 13.11 for listing of airfoils.

13.18 *Wind Tunnel Test Data.* Bound (string) (Size of book 8" × 12"). For airfoils, T–1, Dayton Wright #7, #8, #9, #3. Langley #1, #2, USA #27 (Clark), Clark A, B, Albatross, M II, W.A.L. 26, 27, 28, 29, 30, 31, Sloane, W.A.L. 1, Bauman, Gordon Bennett Racer, Complete G. B. Model, Bauman #2, #3, #1, Hydro Monoplane, Prandtl #223, #225, #227, #242, #244, Gottingen #387, W.A.L. #25, #24, #23, #22, #17, #18, #35, #34, #32, #33. Strut Sections, W.A.L. #36, U.S. St'd Strut, Dayton Wright #3, #2, #1, W.A.L. #21, USA #27, (#27 modified—sharper nose), #27 rear edge cut-out, USA #1, R.A.F. #6, O.W. #1—R.A.F. #6, R.A.F. 15 × .8, #15 × 1.1, #15, #15–2" Gap, #15–3" Gap, #15–4" Gap, #15–5" Gap, #15–6" Gap, USA 27–3 5/16" Gap, R.A.F. #15–3" Gap—⅛" Stagger, #15–3" Gap—1" Stagger, R.A.F. #15–3" Gap—2" Stagger, R.A.F. #15–3" Gap—3" Stagger, R.A.F. #15 (Following surfaces), Fuselage SR3 (Dayton Wright) and several airfoils with flap in down position including USA #27–1" flap—⅛" down, —⅛" down, Clark #1, 1" flap—⅛" down, sketches of large flaps and flap angles, Clark #2, R.A.F. #15 plain, ⅛" down, ¼" down, ⅜" down, ½" down, ⅝" down, ¾" down, 1¼" down, Gottingen #387, ⅛" down, ¼" down, ⅜" down, Photo of drift test models, data of drift measurements, Richardson Pontoon, USA #27.

Tests were made in 1919–20–21. All wing models were 3" × 18". Values indicated for L/D and lift in most cases.

13.19 *Wind Tunnel Test Data.* Bound (string). Size of book 8" × 12". W.A.L. #21, #17, #21, #19, #1, R.A.F. #15 × 1.1, W.A.L. #1 modified to .023" thicker, to .066" thicker, W.A.L. #2, #3, #4, #5, #6, #7, #8, #9, #10, #11, #12, #13, #14, #15, R.A.F. #15 × 1.1 (NOTE: Wood for

smoke tunnel), W.A.L. #16, several Fuselage shapes, O.W. #1—R.A.F. #6 lower, R.A.F. #15 × 1.1—W.A.L. #18—3″ Gap, W.A.L. #18—R.A.F. #15 × 1.1 lower—3″ Gap, 6″ Gap, R.A.F. #15, #15 × .8, #15 + .025″, #15 nose modified, #15 × 1.1, 1½″ Stagger—3″ Gap, #15—2″ Gap, —3″ Gap, —4″ Gap, —5″ Gap, —6″ Gap (2 photos monoplane model). Tests were made in 1919. Wing sizes varied, most are 3″ × 18″, others 10″ × 6″ (low aspect ratio). Values are indicated for L/D and Lift—in some cases for drift.

13.20 *Wind Tunnel Test Data.* Bound (string). Size 6″ × 11″. Test data sheets for airfoils of various shapes, in combination with others (biplane) including, O.W. #1—R.A.F. #6, O.W. #1—R.A.F. #15 × 1.1, R.A.F. #6, USA #1, P8, and drag data on struts. Data show values for L/D, Lift and Drag. Tests were made in 1917, '18, and '19.

13.21 *Graph.* R.A.F. 15 × 1.1—Characteristics—Lift *vs.* Angle for upper and lower surfaces and for each when superposed. Stagger Negative—size 11½″ × 17″. Dated July 9, 1918.

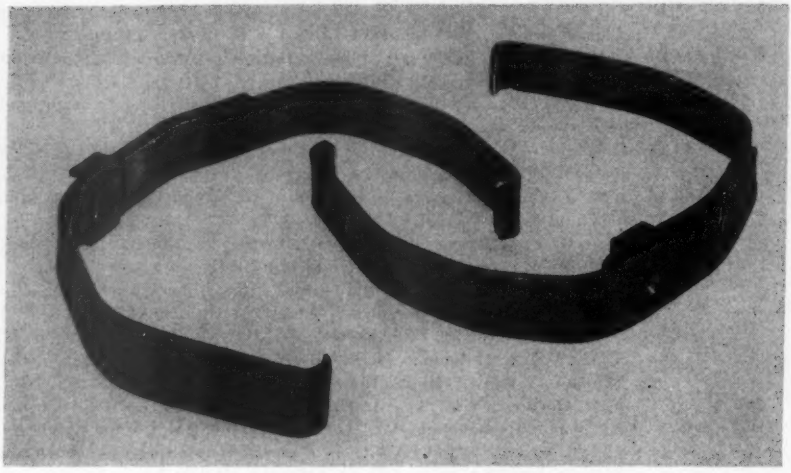


FIG. 13. Mud hooks for automobile wheels. Made by Orville Wright in the 1920's.

13.22 *Graphs.* R.A.F. #15 × 1.1—Lift and L/D *vs.* Angle of Attack. Dated April 26, 1919. Same for superposed R.A.F. #15 × 1.1 with 2″ Gap with curves for both upper and lower. Same for 3″, 4″, 5″, 6″ gap, dated May 22, 1919. Total eight (8) graphs bound with circular punch clips. Size 11½″ × 17″.

13.23 *Graph.* O.W. #1—Lift and L/D *vs.* Angle of Attack. Superposed with 3″ Gap. Curves for monoplane and upper and lower wings. Size 11½″ × 17″. Dated May 12, 1919.

13.24 *Graphs.* R.A.F. #15. Lift and L/D *vs.* Angle of Attack. Superposed with 2″, 3″, 4″, 6″ gap and one not specified gap. Curves for upper and lower surfaces. Size 11½″ × 17″. Dated December 12, 1919. Total 5 graphs—paper clip bound.

13.25 *Graphs.* R.A.F. #15. Lift and L/D *vs.* Angle of Attack. Superposed airfoils with 2″, 3″, 4″, 5″, and 6″ Gap. Curves for upper and lower surfaces. Size 11½″ × 17″. Dated December 12, 1919. Total 5 graphs bound with circular punch clips.

13.26 *Graphs.* R.A.F. #15—Lift and L/D *vs.* Angle of Attack. Superposed airfoils with 3″ gap and ½″, 1″, 2″, and 3″ stagger. Curves for upper and lower surfaces. Size 11½″ × 17″. Dated December 15, 1919. Total 8 graphs bound with circular punch clips.

13.27 *Graph.* USA #27, Lift and L/D *vs.* Angle of Attack. Superposed airfoils with 3 5/16″ gap. Curves for upper, lower and monoplane surfaces. Dated Nov. 9–10, 1920. Size 14″ × 22″.

13.28 *Graph.* R.A.F. #15—L/D *vs.* Lift. Size 11½″ × 17″. No date.

13.29 *Graph.* R.A.F. #15 × 1.1.

13.30 *Graph.* "T 1" Tapered Wing. Clark (USA 27C) Tapered wing—L/D *vs.* lift. Size 11½″ × 17″—T 1 May 19, 1922, Clark Dec. 13, 1920.

13.31 *Graph.* Bauman Gordon Bennett Racer. L/D *vs.* Lift. Size 11½″ × 17″. Dated Mar. 9, 1921.

13.32 *Graph.* Clark "A," Clark "B." L/D *vs.* Lift. Size 11½″ × 27″. Dated Dec. 17, 1920.

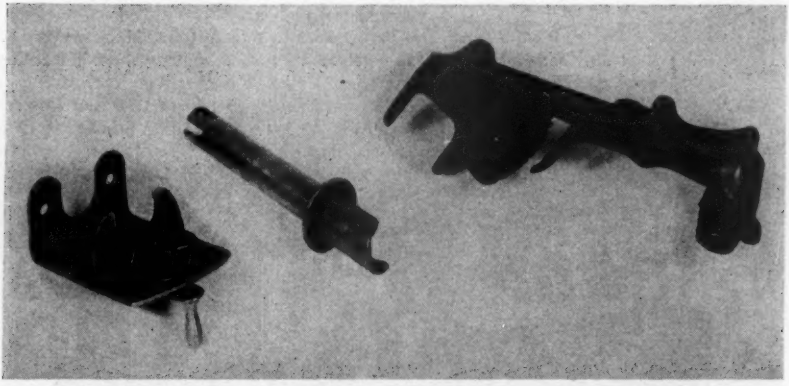


FIG. 14. Lever cam and sleeve used in the 1903–1905 plane to control spark timing (left). On right is foot control to Mea-magneto on the 1910 biplane.

13.33 *Graph.* Bauman. L/D *vs.* lift. Size 11½″ × 17″. Dated Feb. 5, 1920.

13.34 *Graph.* USA #27 (#2 Surface) (Modified—sharper nose). L/D *vs.* Lift. Size 11½″ × 17″. No date.

13.35 *Graph.* USA #27 (#1 Surface). L/D *vs.* Lift. Size 11½″ × 17″. No date.

13.36 *Graph.* Clark, W.A.L. #1, R.A.F. #15, Bauman (high lift), Bauman (hydroplane wing), Prandtl #225. L/D *vs.* Lift. Size 11½″ × 17″. No date.

13.37 *Graph.* W.A.L. #22, #24, #35, #17, #18, #35, #21, R.A.F. #6, M-II. Center of Pressure *vs.* Angle. Size 11½″ × 17″. Dated April 8, 1920.

13.38 *Graph.* R.A.F. #15 Superposed Chord Gap. L/D *vs.* Speed × Minimum Speed. Size 8½″ × 12″. No date.

13.39 *Graph.* R.A.F. #15 and Clark. L/D *vs.* Speed. Size 8½″ × 12″. Dated Nov. 29, 1920.

13.40 *Graph.* M–II, Sloane, Bauman, R.A.F. #15, W.A.L. #1, USA #1. L/D *vs.* Speed. Size 11½″ × 17″. No date.

13.41 *Graph.* R.A.F. #15 (Superposed 1″ Stagger Chord Gap), R.A.F. #15 (Superposed Chord Gap). L/D *vs.* speed. Size 11½″ × 17″. No date.

13.42 *Notes. Wind Tunnel Test Data.* Measurements made from May 28, 1917 to June 12, 1917. Includes 3″ × 3″ square plane, 6″ × 6″ square plane,

1" upright 24" long, various uprights of different cross section, and several airfoils. Size 5" × 10½". Bound by paper clips. 16 pages.

13.43 *Notes. Wind Tunnel Test Data.* Measurements taken from July 2, 1917 to August 25, 1917. Includes data on R.A.F. #6, R.A.F. #3, R.A.F. #2. Lift and Drift for various Angles of Attack. Bound by wire. 16 pages. Size 5" × 10½".

13.44 *Notes. Wind Tunnel Test Data.* Measurements taken from August 25, 1917 to October 19, 1917. Includes data on R.A.F. #6–2, O.W. #1, #25, R.A.F. #6, Superposed Gap = Chord, USA #1, R.A.F. #6–3, –4, –5. Lift and Drift for various Angles of Attack. Bound by wire. 24 pages. Size 5" × 10½".

13.45 *Propeller Test Data.* For 7, 8, 9, 10, and 11 ft. diameter propellers at various speeds and horsepowers. Pages (219) string bound. Size 6" × 9". No date.

13.46 *Sheet. Wind Tunnel Test Data.* W.A.L. #2 Airfoil. Made May 8, 1919. Size 7" × 11". On notebook form sheet same as those in 629.133 Wr 13.42.

13.47 *Sheet. Wind Tunnel Test Data.* W.A.L. #18 Airfoil. Made in May 8, 1919. Size 7" × 11". On notebook form sheet same as those in 629.133 Wr 13.42.

13.48 *Graph.* W.A.L. #2 and W.A.L. #18. Rough plot of L/D and Lift *vs.* Angle of Attack of data on 629.133 Wr 13.46 and 13.47. Size 8½" × 12".

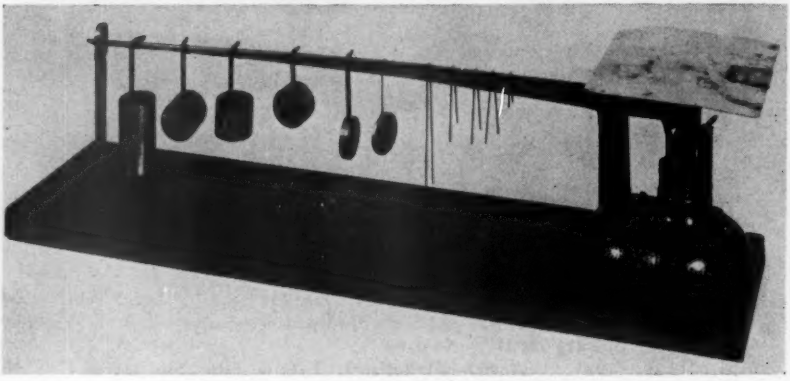


FIG. 15. Scale and weights made by Orville Wright.

OTHER WIND TUNNEL MODELS

48–44–7 *Model Airplane.* Wind tunnel model. Size: span 18½", length 13", height 3". Monoplane (Dayton Wright), Fuselage of rectangular cross section.

48–44–8 *Model Airplane.* Wind tunnel model (Dayton-Wright), for Gordon Bennett Racer. Monoplane. Size: span 17½", length 16½", height 4".

48–44–9 *Model Airplane.* Split flap, wind tunnel model. Biplane, 1920. Size: span 20¼", length 13½", height 3½".

48–44–10 *Streamline Shape Wind Tunnel Model.* Size: Length 29", max. dia. = 6".

48–44–17 *Smoke Ejector.* Hollow streamline metal tube ½" wide × 4" long with 14 small holes through trailing edge. Over-all length 10" including mounting rod.

48–44–18 *Smoke Ejector.* Hollow streamline metal tube ¾" wide × 4½" long with glass tube extending 1¾" from one end. Twenty seven (27) holes through trailing edge.

NOTE: Surfaces between holes are grooved.

48–44–19 *Airfoil.* Smoke experiments. Heavy flat plate 2½". Chord × 4" span, ¼" thick. Hollow tube extends at mounting lug end. Connects to small hole in one surface.

48–44–20 *Airfoil.* Smoke experiments. Flat Plate 3" chord × 3" long. $\frac{3}{64}$" thick. Beveled edges around one face.

48–44–28 *Pitot Tube.* Standard type with dynamic and static openings and two tube connectors. Size over-all, 8" × 6" × ¾". Tube dia. = ½". Date about 1917.

SCALE AND WEIGHTS

48–44–11 *Scale and Weights Made by Orville Wright.* Mounted on wood base 19¾" × 5". Height 5¾".

Six (6) weights. One marked 1 oz., using the scale the other five weights measured, ½ oz., 2 oz., 4 oz., 4 oz. and 8 oz. The lever arm is graduated 1 to 8 with 1¾" between consecutive graduations. Weights are steel 1" in diameter and ⅛", ¼", ½", ⅝", ¾" and 1⅛" in thickness.

Five (5) wire weights (bent) one of 1/25 oz., three of 1/50 oz. and one of 1/100 oz.

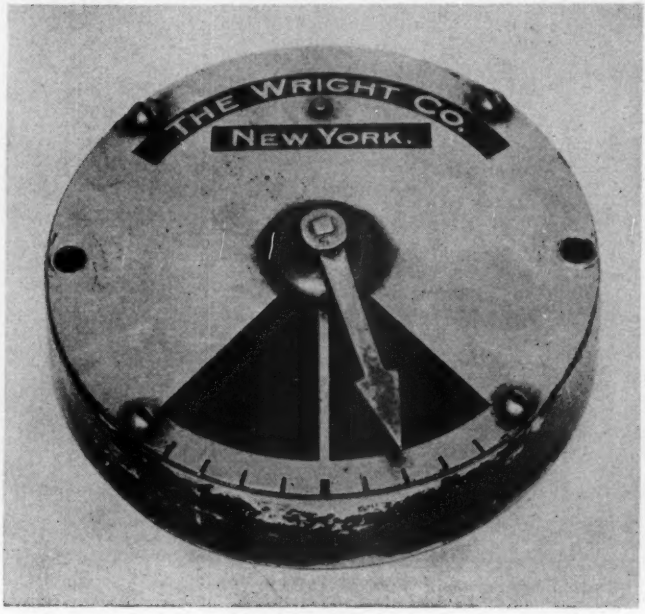


FIG. 16. Bank indicator.

ENGINE PARTS

48–44–12 *Spark Control Unit.* Foot operated, for 1910 Wright Engine. Size: 6" long, 3½" wide, 2" in depth. Metal. Ratchet and Paul for adjustable setting.

48–44–13 *Valve Assembly.* Piece for lower end valve box auxiliary exhaust motor (like one at Ford). Size: 2¾" max. diameter, 4" long.

48–44–14 *Valve Guide.* Piece for lower end valve box auxiliary exhaust motor (like one at Ford). Never used, not completed. Size: 3¾" max. diam., 2½" long.

48–44–15 *Spark Control Unit.* For vertical motor of 1903–05, make and break spark adjustment. Two pieces, size: 1" max. diameter, 4" long; other piece 3" long, 1¾" wide, 1¾" thick.

48–44–16 *Drive Shaft and Bushing.* For oil pump. Size: 5⅜″ long, 1⅜″ max. diameter; other 2⅛″ long, 1¼″ max. diameter.

HUB AND PULLEYS

48–44–21 *Pulley and Bracket.* Pulley 2½″ diameter × ¼″ thick, brass. Bracket size 1¾″ × ¾″ × 1″ wide.

48–44–22 *Pulley and Bracket.* Pulley 1½″ dia. × ⅛″ thick, brass. Bracket size 2⅛″ × 1″ × ⅛″ thick.

48–44–23 *Hub.* For truck used to launch airplane. One of two hubs used. Not used on December 17, 1903 but used November 24, 1903. Given to Orville Wright at Kitty Hawk in 1928. Size 5¾″ × 5″ × 1¾″.

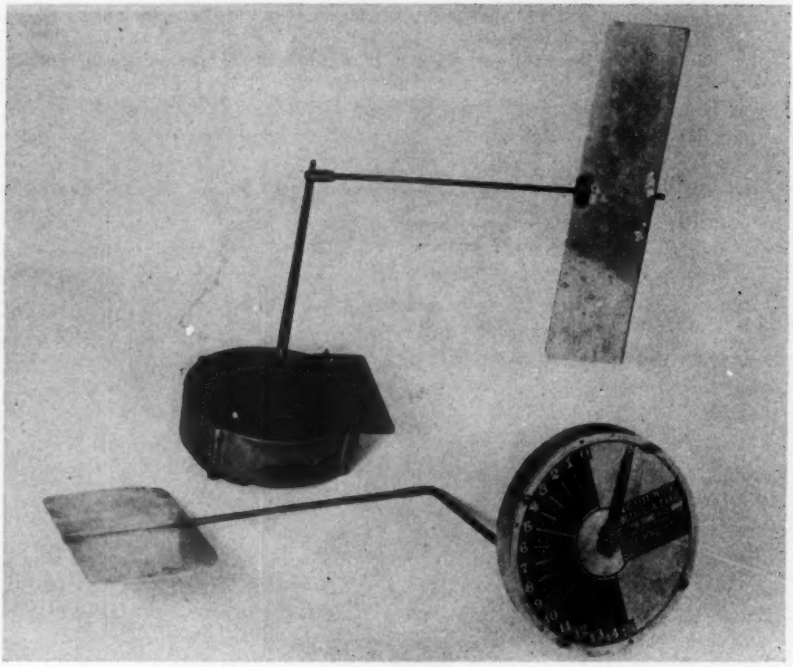


FIG. 17. Incidence indicators.

INSTRUMENTS

48–44–24 *Diaphragm Assembly.* Double metal diaphragms connected to linkage, two outlets for hose connection. Size 5¼″ diameter—1⅝″ wide.

48–44–25 *Bank Indicator.* Nameplate, The Wright Co., New York. Size: 3″ dia. × ⅛″ thick. Pointer connected internally to pendular weight. Graduated scale at bottom. Date, approx. 1914.

48–44–26 *Incidence Indicator.* Nameplate, Mfg. by the Wright Co., Dayton, O., USA. Vane type with internal counterbalance. Gear drive to pointer. Scale graduations 0 to 15 in 180°. Size: 17¾″ × 14″ × 6″ over-all. Indicator face 6″ in diameter.

48–44–27 *Incidence Indicator.* Early model about 1912. Vane type (see 48–44–26). Over-all size: 16½″ × 15″ × 6″.

AUTOMATIC CONTROL DEVICES

48–44–31 *Wing Balancing Device.* Noted as Orville Wright Automatic 1910–1911. Two bladed unit with adjustable pitch mechanism. Believed to be a part of the automatic lateral stability device for which Orville Wright was awarded the Collier Trophy in 1913. Blades 32″ in diameter, over-all length 37″ × 5″ high. Wooden blades and base plate.

48–44–32 *Experimental Model of an Electrical Control Device.* Noted as Orville Wright Automatic 1918–1942. Over-all size: 28″ × 10″ × 20″ high. Mounted on wood base

48–44–33 *Valve.* For Automatic Control Device. Over-all size: 8″ × 7″ × 1½″. Two valves connected to ¼″ copper tubing with bleed-off center tube.

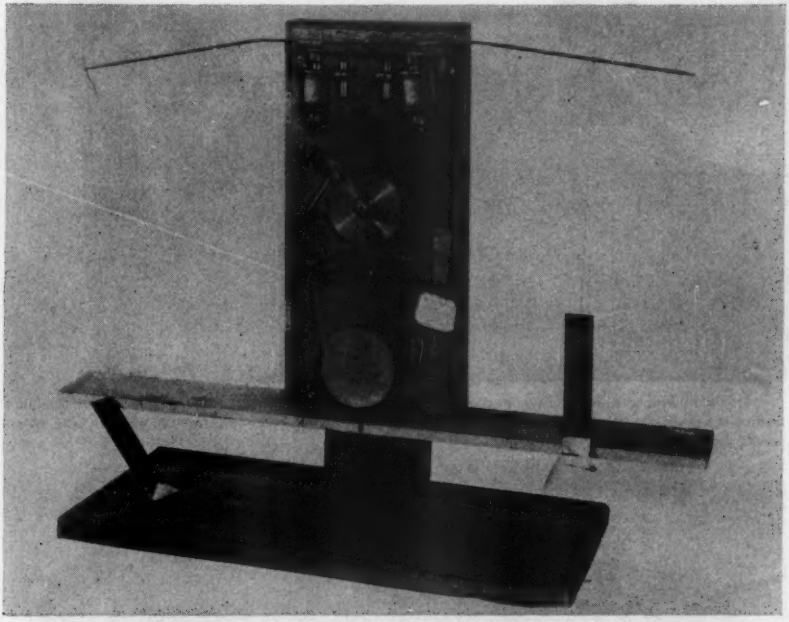


FIG. 18. Experimental model of an electrical control device for airplanes.

48–44–34 *Control Cylinder.* Used in 1918 to operate the wing warping stick. Over-all size: 24½″ long × 4″ wide × 2″. Large cylinder 2″ diameter, small cylinder 1½″ diameter.

48–44–35 *Bellows.* Two bellows mounted to a 2″ × 1″ wood member 11½″ long. Pressure inlets to bellows and lever interconnection to pointer. Dated 1928. Believed to have been used in automatic control experimental work. Over-all size: 14″ × 5½″ × 2″.

48–44–36 *Pendular Device.* Experimental apparatus probably used during O.W.'s automatic control investigations. Includes an acceleration compensating mechanism. Over-all size: 7″ × 10″ × 3″.

48–44–37 *Pattern.* Housing for autopilot pendulum. 2 pieces, cover, and housing. Over-all size: 7½″ × 5″ × 1⅜″. Made of wood.

48–44–38 *Landing Device.* Automatic. Dated 1943. Mechanism mounted in a wing section of 16½″ chord, 4″ thick and 2″ wide.

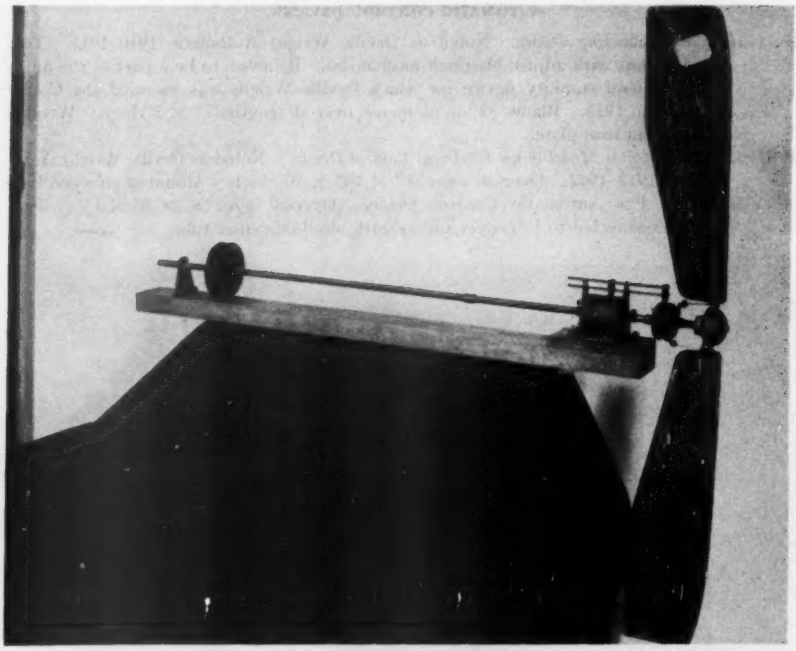


FIG. 19. Power unit used by Orville Wright to achieve automatic lateral stability in 1910. A pendulum operated the rotating cam which controlled the blade pitch to supply a force to operate the wing warping system through the pulley at the end of the shaft.

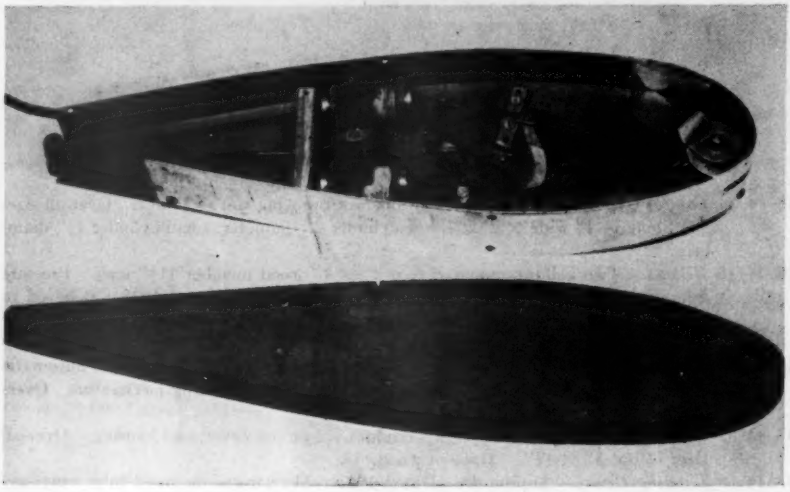


FIG. 20. Automatic landing device.

629.133 Wr 16.11 *Diagram.* Wiring diagram noted X-ray. Appears to be for automatic control device. No date. Size: 5″ × 9″. Brown wrapping paper.

CYPHER MACHINE

48–44–39 *Cypher Machine.* Dated 1944. Machine made by Orville Wright for automatic selective coding of messages. Over-all size: 9″ × 9″ × 5″. Combination of gears, cams, linkages mounted on wooden U piece.

48–44–40 *Coding Boards for Cypher Machine.* Two boards with 6 dials each used for coding and decoding messages. Size #1 is 22″ long × 3¾″ wide; size #2 is 18″ long × 3″ wide. Wood bases are ¼″ thick. Instructions for coding and decoding are given as follows:

Cypher Machine No. 3. All disks turn to right, or clockwise, except No. 4 which turns both left and right.

To Code:

Turn disk No. 3 to first letter of message.
Turn disk No. 2 and No. 4 same number of spaces. This gives first cypher letter.
Turn disk No. 4 to the left the number of spaces indicated by the smaller red numbers in red on Nos. 5 and 6.
Turn disk No. 5 to right red number on No. 4.
Turn disk No. 6 to right red number on No. 3.
Turn disk No. 1 the number of spaces indicated by the smallest of the block number on Nos. 3, 4, 5, 6.
Turn disk No. 2 block number on No. 1.
Turn disk No. 3 to next letter of the message.
Turn disk No. 2 the same number of spaces. (Record second code letter.)

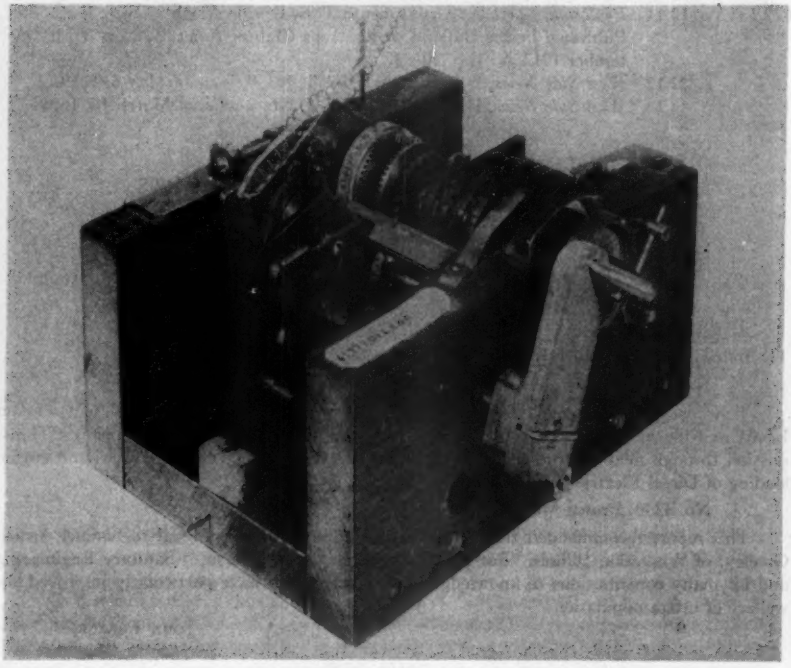


FIG. 21. Cypher machine.

To Decode:

Turn No. 2 to first letter of code.
Turn No. 3 same number of spaces. (Record message letter at top of dial on No. 3 which is first letter of original message.)
Turn No. 4 to right same number of spaces as No. 3.
Turn No. 4 to left the smaller red number of Nos. 5 and 6.
Turn No. 5 to right red number under No. 4.
Turn No. 6 to right red number under No. 4.
Turn No. 1 to smallest black number on Nos. 3, 4, 5, 6.
Turn No. 2 black number on No. 1 under 26.
Turn No. 2 to second letter in code.
Turn No. 3 same number of spaces (Record second message letter at top of dial No. 3, etc.)
Disk No. 2 gives cypher letters.
Disk No. 3 gives message letters.

References to numbers on disks are to the numbers at top of disks.

HYDRAULIC PUMP

629.133 Wr 11.11 *Drawings.* Wright Hydraulic Pump. Collection of drawings and notes concerning a wobble plate type of hydraulic pump and control device.

MISCELLANEOUS ITEMS

48–44–29 *Mud Hooks for Automobile Wheels.* Made by Orville Wright in the 1920's. Two pairs. Over-all size: $8\frac{1}{2}'' \times 7'' \times 1''$. Made from $\frac{1}{4}'' \times 1''$ metal strap.

48–44–30 *Hub for Fan Brake used in Testing Engines.* Metal. Over-all size $14'' \times 5'' \times 2''$ wide.

48–44–41 *Miscellaneous Parts.* Small box of miscellaneous small parts, weights, etc.

629.133 Wr 12.11 *Photostat.* Article, "Otto Lilienthal" by Orville Wright. Size: $17'' \times 13''$. Published in the Bulletin of the Aero Club of America, New York, September 1912, V. 1, p. 20–21.

12.12 *West Side News*, Dayton, Ohio, Vol. I, No. 9, issue of May 5, 1889.

12.13 *West Side News*, Dayton, Ohio, Vol. I, No. 2 issue of March 16, 1889.

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, June 13, 1951.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JUNE 13, 1951.

DR. RUPEN EKSERGIAN in the Chair.

The following reports were presented for final action:

No. 3236: Henderson Medal.

This report recommended the award of the George R. Henderson Medal to Hermann Lemp, of Ridgewood, New Jersey, "In view of his basic contributions to the Electric Transmission through field control, thereby improving the performance characteristics and engine loading of Diesel Electric locomotives."

No. 3239: Brown Medal.

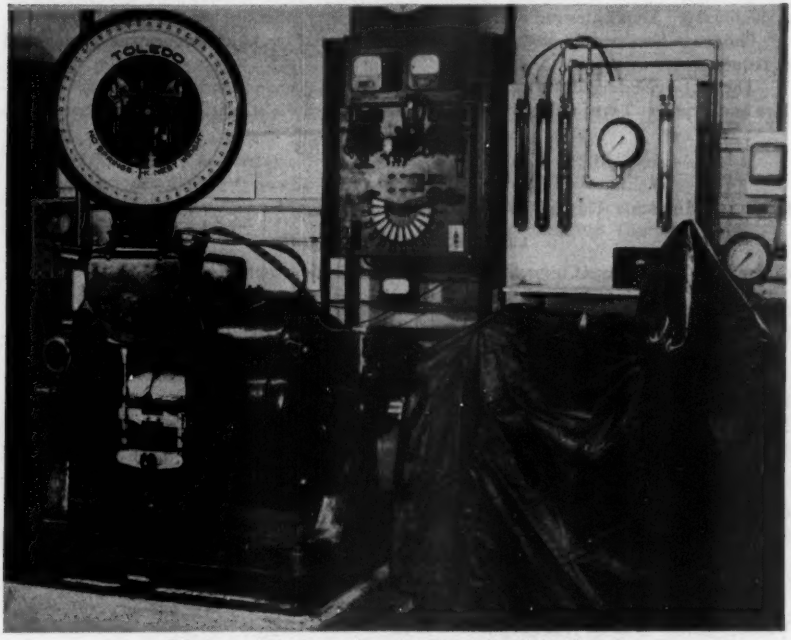
This report recommended the award of the Frank P. Brown Medal to Samuel Arnold Greeley, of Winnetka, Illinois, "For his leadership in the profession of Sanitary Engineering and his many contributions to knowledge in that field which have particularly improved the welfare of urban populations."

JOHN FRAZER,
Secretary to Committee.

THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

ESTABLISHMENT OF APPLIED HYDRAULICS SECTION

The Applied Hydraulics Section of the Mechanical Engineering Group has been established in the Laboratories to promote the field of applied hydraulics. To provide industrial concerns and government agencies with facilities for research in applied hydraulics, there are available a qualified analytical unit, personnel especially trained in applied hydraulics, and a modernly equipped hydraulics laboratory. Although current investigations deal with positive displacement hydraulic machinery and pivoted-shoe oil-film bearings, the personnel and facilities are capable of handling research and development problems associated with applied hydraulics and fluid mechanics in general. Some of the branches of fluid mechanics into which the section hopes eventually to expand are hydraulic packing, agitation and mixing, and hydraulic controls. Equipment has been installed to conduct experimental investigations on hydraulic components such as pumps, motors, valves, cylinders, packing, and systems.



This dynamometer is one of numerous items of special equipment installed in the new Hydraulics Laboratory.

The Applied Hydraulics Laboratory is equipped with a d-c. dynamometer of 45-hp. capacity as an absorption generator and of 37-hp. capacity when used as a motor with a speed range from 1200 to 2500 rpm. (See photograph.)

A high pressure pumping unit is used as a source of fluid power for test work on cylinders, valves, and packings. This unit is a constant displacement, radial piston pump with a capacity of 10 gallons per minute at 5000 psi. It is expected that an intensifier will be used with this unit later to obtain pressures up to at least 50,000 psi. A smaller pumping unit provides fluid power up to 1000 psi. This unit has a vane type pump of 1 gallon per minute capacity.

In addition to measurements with the usual Bourdon tube gages of assorted pressure ranges and with manometers, determination of dynamic pressures of high frequency can be made with a diaphragm pick-up and electronic recording apparatus.

Temperature-measuring equipment consists of the usual bulb type of thermometers and thermocouple indicators.

A dead-weight tester, with a range of 0 to 3000 psi., is available for calibrating Bourdon tube gages and for hydrostatic testing of components.

Work currently being undertaken in the Applied Hydraulics Laboratory consists of the application of pivoted-shoe oil-film bearings to improve the performance of hydraulic transmissions. A compressor of new design is being tested on the dynamometer. Also, special pivoted-shoe thrust bearings which use unconventional lubricants are being developed for special purpose machinery.

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open 9 A.M. until 5 P.M. on Mondays, Tuesdays, Wednesdays and Fridays; 2 P.M. until 10 P.M. on Thursdays; and 9 A.M. until 12 noon on Saturdays.

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PATAI, IMRE AND MARTIN A. POMERANTZ: Contact Potential Differences.
KNOWLES, T. AND A. H. TAYLOR: Spectral Radiation Involved in Photoreactivation of Ultraviolet-irradiated Cultures of Micro-organisms.
SPENCER, DOMINA EBERLE AND VINCENT J. STAKUTIS: The Integral-Equation Solution of the Daylighting Problem.
KRZYWOBLOCKI, M. Z.: On the Foundations of Certain Theories of Turbulence.
SYMONDS, P. S.: Recent Progress in the Plastic Methods of Structural Analysis.
MANDEVILLE, C. E.: The Slow Neutron Induced Radioactivity of Nuclear Explosions.
GEORGE, E. F.: Light—Inadequacy of the Ultraviolet Theory of Ionization in the E-Layer.
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SILBERSTEIN, LUDWIK: Superposition of Mixture of Simple Quantic Characteristic Curves of Photographic Emulsion Layers.

MUSEUM

When Solomon confessed that there were four things which passed his comprehension, he was wise enough to include "the way of a ship in the midst of the sea" among the incomprehensible things. Ocean travel is so safe, so quick, and so certain today that the voyager rarely stops to think about the methods employed by the navigator to find his way unerringly over the trackless wastes of water. Still more wonderful is the manner in which the seafarer of Solomon's days and long afterwards was able to find his way without instruments. How, for example, did the Vikings find their way from land to land in order to reach America? For they must have been out of sight of land for days at a time. Moreover, they had to make their way back to the home ports. Granting that they used land-sighting "searavens" (shags or cormorants) and that they were close observers of the sky, there is still an atmosphere of wizardry surrounding their skill.

Coming down to the great Age of Discovery we are better informed upon the instruments and methods used in navigation, but it still remains something of a mystery how seafarers like Columbus, Hudson, and Magellan were able to sail on prescribed courses and return. The visitor to the Museum is recommended to seize the opportunity of examining the nautical instruments in the Marine Section and to allow his mind to roam in speculation upon that question which baffled Solomon.

The astrolabe was the first instrument adapted to navigation but it is a matter of conjecture how many mariners were instructed enough to make intelligent use of it. The magnetic compass was not employed in recognizable form until toward the end of the fourteenth century but it is a remarkable fact that the conventional *fleur de lys* used today to mark the north point is a survival from the earliest compass cards used on board ship. The Kelvin compass displays a great advance upon the earlier instruments, for not only had it been scientifically established that the magnetic compass was liable to variation and deviation, but the practice of building ships of iron and steel had introduced perplexing problems associated with the magnetic attraction of the metal used in construction. The Kelvin compass marks an era in the navigating compass and the next revolutionary step was not made until about 1910 when the gyroscopic compass was developed by Elmer Ambrose Sperry.

The "gyro" compass works independently of the earth's magnetism and is unaffected by the magnetic attraction of the iron and steel structure of the ship. The needle points unfalteringly to the true north, so that no corrections have to be made for deviation or variation. One of the later developments of this highly ingenious device permits the vessel's course to be laid upon a chosen bearing, and the ship's head is held automatically on that bearing. This automatic control is not used in busy water or in winding channels where frequent adjustments of the helm are required. It is reserved for use when the ship's course can remain constant over long distances.

The compass is but one of the instruments adapted to navigation which may be seen in the Marine Section of the Museum. This small, but probably unique collection of instruments is well worthy of attention since it shows how progress has been made over the centuries in a science which is being improved constantly through developments in the field of electronics. The mystery is still there, but it has shifted from the art of the navigator to the science in the construction of his instruments. Unlike the sea itself which is as unchanging as time, the art and science of conquering it is a gradually developing process.

BOOK REVIEWS

PULSE TECHNIQUES, by Sidney Moskowitz and Joseph Racker. 300 pages, drawings, 15 × 22 cm. New York, Prentice-Hall, Inc., 1951. Price, $5.00.

Because of the growing complexity of most engineering subjects every opportunity should be taken to organize our knowledge. The frequent occurrence of pulse phenomena in modern electrical engineering suggests an opportunity to analyze them as a group. Considerable advantage may be gained by such a grouping because the techniques for solving circuit problems involving pulse phenomena are somewhat specialized.

Further justification for the need of published data on pulse techniques is recognized in view of the significance of multiplex relay systems, television, radar and electronic computers. All of these have reached eminence during the past decade and are not treated specifically in the earlier standard works on communications. More recent publications on the individual subjects mentioned have not coordinated the information relative to pulse techniques because they were more directly concerned with the particular application being treated. For instance, books on television have not discussed related circuits found in radar practice, and vice versa. Therefore, it has not been possible to refer to a single text and find a complete record of methods. On the contrary, it has been necessary to examine texts dealing with several branches of electronics and to evaluate numerous approaches to the common problems.

Moskowitz and Racker have sensed the situation described above and have prepared a small book devoted to several aspects of pulse circuits. Except for two brief chapters at the end of the book devoted to pulse communication systems and aerial navigation aids the authors have directed their attention toward producing a general treatise of pulse techniques suitable for most applications.

The sections on pulse communication and aerial navigation aids serve only as very general illustrations and contribute little to the stated purpose of the text. There are also several appendices. When these have been subtracted from the book's three hundred pages, one is left with only two hundred and twenty pages. This space constitutes the main body of the book in which the authors discuss the mathematical representations necessary for transient analysis, circuit design of pulse networks including pulse shaping, passive networks, amplifiers, pulse generation and finally, measurements. Needless to say, the treatment of all these subjects is brief. However, the authors have presented sufficient fundamental material that the student should be able to proceed beyond the examples given.

The book is apparently intended as a text for a brief, undergraduate course in the pulse aspects of electronics. Problems are given at the end of all chapters. Realizing the need for a reference book on the general topic of pulse techniques, the authors have made a start toward the fulfilment of this need although it will remain for subsequent editions to produce such a volume if it is to be done. Since the subject itself is young, it would require a rather remarkable career for an author to have been exposed to the large variety of professional experience concerning pulse applications in such a few years. The book is, nevertheless, a welcome addition to the electrical engineering literature and is prepared in a compact and useful form.

C. W. HARGENS

THE FISCHER-TROPSCH AND RELATED SYNTHESES, by Henry H. Storch, Norma Golumbic, and Robert B. Anderson. 610 pages, illustrations and diagrams, 15 × 24 cm. New York, John Wiley & Sons, 1951. Price, $9.00.

In the Fuel Research Laboratory of the Kaiser Wilhelm Institute at Muelheim Ruhr, Germany, Franz Fischer and Hans Tropsch in 1923 disclosed that alkalized iron turnings catalyzed the hydrogenation of carbon monoxide to a mixture of paraffin oils and oxygenated compounds when the reaction was carried out under high temperatures and pressures. Since

the objective of German research at that time was the production of substitutes for gasoline and motor fuel, Fischer and Tropsch were assigned to investigate this reaction thoroughly as a possible source of motor fuels. After years of experimental work, they succeeded in discovering optimum ranges of temperature and pressure and catalyst type to produce mixtures of branched and straight chained hydrocarbons suitable for use as fuel oil.

After the defeat of Germany in 1945, teams of British and American scientists thoroughly studied German documents and questioned German scientists. A large mass of technical and engineering data was collected in this manner, and a critical review of the data on the Fischer-Tropsch and related syntheses is presented in the six chapters of this book.

Chapter I presents the structure and reactivity of hydrogen, carbon monoxide, iron, nickel, and cobalt, and the thermodynamics of the Fischer–Tropsch process. Methods of preparation and properties of heterogeneous catalysts are described in Chapter II. The developments of Fischer-Tropsch catalysts and the development of the process itself are presented in Chapters III and IV. Chapter V deals with processes related to the Fischer-Tropsch synthesis, namely, the oxo-process and the iso-paraffin synthesis. The final chapter presents the kinetics and various proposed reaction mechanisms for this synthesis.

This book offers a complete and well organized account of the very important Fischer-Tropsch process, and it also provides an interesting and informative discussion of theoretical and applied contact catalysis. Data such as reactor sizes, operating pressures, and gas flow rates will be of partucular interest to engineers working with this process. The usefulness of this book should parallel the growth in importance and applicability of the Fischer-Tropsch process. It is to be highly recommended as a work book for research engineers in the field, and as a valuable addition to any scientist's bookshelf.

D. H. RUSSELL

JOHANNES KEPLER: LIFE AND LETTERS, by Carola Baumgardt. 209 pages, port., 16 × 24 cm. New York, Philosophical Library, 1951. Price, $3.75.

Of the four great founders of modern astronomy and physics—Copernicus, Kepler, Galileo, and Newton—the least well known is Kepler. The neglect into which he has fallen is not easy to understand, for we have had for the past twenty years the readily accessible collection of Kepler's letters edited by Caspar and Von Dyck. This rich mine of information has not been worked and Kepler remained a somewhat shadowy figure to English-speaking readers. Mrs. Baumgardt's book removes this reproach and we have at length a short but complete life of Kepler.

It is not possible to make any evaluation of the work of a scientist who died three hundred years ago unless he is viewed against the background of his own times. When we are able to read his own letters we are better able to perceive how significant were contemporary thoughts and events in his own eyes, undistorted by any haze of time. Mrs. Baumgardt has made good use of Kepler's letters, knitting her selection together with brief contributions of her own to preserve the continuity of her subject.

Kepler was an unusually interesting letter writer and some of his letters are worthy of a place in any anthology of that literary form, as for example, the letter to Tobias Scultetus printed on page 102 of this book. Letters reveal the writer's character, and Kepler emerges from this test as a man of great benevolence, tolerance, and humor. Fortunate it was that he possessed these qualities, for he had need of them throughout his whole life, which was a continuous struggle. He never displayed any interest in social or political prestige. One gathers the impression that he regarded these as distractions from the work which absorbed his mind. All he asked was the means to concentrate upon research work. "The only honor I recognize as such is that bestowed by Providence which allowed me to make use of Tycho's observations."

Kepler's modest request to be allowed to continue his work undisturbed was never granted. He held a position of social distinction in Prague and he was granted an adequate salary—on paper. Too many of his letters were pleas to influential people soliciting their aid in securing for him some payment of a salary he had earned years before, had been promised again and

again, but was always withheld. Lack of financial security was not his sole trouble through life. The story of religious persecution is not uncommon among the pioneer supporters of the Copernican theory, but Kepler had the unique distinction of being harried by Catholics and Protestants alike. His obstinate adherence to beliefs which caused him to be regarded as a heretic by his co-religionists not only caused him acute personal distress, but it closed the doors of the one university in which he always hoped to be called to a professorial chair. In spite of his struggle for physical existence and his exclusion from communion with his church, he was a prodigious worker. No less than twenty-six of his works are cited in this book.

Short though Mrs. Baumgardt's book is, it is the fullest available biography in English, and if for no other reason deserves to be read. But the author has made such judicious choice of her material that the book is likely to stand as a capable study against the assault of more bulky competitors. A word of praise is due the publishers who have furnished a setting which is a pleasure to read. Author and publishers are to be congratulated on giving us a delightful addition to the scientific bookshelf.

T. C.

INTRODUCTION TO THE STUDY OF AIRCRAFT VIBRATION AND FLUTTER, by Robert H. Scanlan and Robert Rosenbaum. 428 pages, illustrations, 16 × 24 cm. New York, The Macmillan Co., 1951. Price, $7.50.

This book is aimed to serve two types of readers: first, the practicing engineer who requires an acquaintance with modern techniques of aircraft dynamics, and second, senior or graduate engineering students of aircraft vibrations and flutter.

An introductory chapter covers basic mathematical techniques such as operations with matrices and determinants, solution of sets of linear equations, and solutions of higher degree equations. This is followed by a chapter on Lagrangian equations of motion, their application in writing the equations of motion of vibrating systems, ending in the presentation of the equations of motion in matrix form. The matrix required to diagonalize the dynamic matrix is developed, to yield the equations of motion in the normal coordinates.

After a study of linear systems in one and two degrees of freedom, the classical flutter problem is introduced as an example of self-excited oscillations. Methods of examining stability of such systems are discussed.

Basic beam relationships including the expressions for kinetic and potential energies, Castigliano theorems, reciprocity theorem, and influence coefficients are given in Chapter VI. Methods for determining influence coefficients of practical wings are outlined.

Lateral and torsional vibration of beams and the important approximation methods of Rayleigh, Rayleigh-Ritz, Stodola, Holzer, and Myklestad for calculating frequencies are given in Chapter VII. Matrix iteration methods employing influence coefficients are also described.

General two-dimensional flutter theory is considered in Chapter VIII. After development of expressions for kinetic energy, potential energy, and dissipation function, the equations of motion are derived for a system comprising wing bending, wing torsion, and aileron motion about the hinge line. Expressions for calculating the aerodynamic forces are given. Derivation of the stability determinantal equation concludes the chapter. The theory is extended in Chapter IX to three-dimensional flutter (where the spanwise variation of mass, geometry, and vibration mode shape are included). Chapter XII develops flutter analysis in terms of the normal modes.

An entire chapter is devoted to interpretation and methods of solution of the flutter stability determinantal equation. Tabular methods are emphasized.

Wing torsional divergence and control surface reversal are discussed. A chapter on instrumentation and testing covers practical equipment and methods for experimental study of vibration and flutter of aircraft structures. A concluding chapter extends the flutter theory to swept wings.

The intent of the authors is to present a resume of representative engineering practice in the American aeroelastic field. Measured in terms of this intent, the book is highly successful.

HOWARD H. BROWN

FUELS AND COMBUSTION HANDBOOK, edited by Allen J. Johnson and George H. Auth. First edition, 915 pages, illustrations, 15 × 24 cm. New York, McGraw-Hill Book Co. 1951. Price, $12.50.

To begin with a criticism, it is believed that this handbook should be entitled *The Generation of Heat and Power for Industrial Purposes* or *The Economics of Heat and Power Generation for Industry*. Notwithstanding the somewhat misleading title, this handbook is a gold mine of practical information on the subject of the selection and efficient utilization of fuels used by industries. The material is divided into eight sections and to adequately indicate the scope, the titles of these sections along with some of the chapter headings are given here.

Section 1. Solid Fuels. Information in this section covers fuel sources, trends and reserves; the characteristics of Pennsylvania and other anthracites, bituminous and subbituminous coal, lignite, peat, wood, wood wastes, charcoal, agricultural wastes, manufactured solid fuels, cokes, and briquettes.

Section 2. Liquid and Gaseous Fuels and Miscellaneous Sources of Heat and Power. In this section one finds data on petroleum and its derivatives, coal-jn-oil fuels, petroleum products from shale, synthetic motor fuels, natural gas and manufactured gases. It is a little surprising to find a chapter at the end of this section on electric heating, water power, power from ocean waves, the wind as a source of power, solar heat, thermal springs, thermit, and atomic energy.

Section 3. Combustion. Most of the reference data needed for combustion engineering calculations are included in this section. An excellent series of nomographs is presented in a chapter on the calculation of heat balances. Also included in this section are chapters on chimney design and on combustion rejects, such as, smoke, fine dusts, and slags.

It is believed that the part of this section on fundamentals of combustion could be greatly improved. The material on flame is inaccurate and should be rewritten for any future editions.

Section 4. Selection of a Fuel. The factors involved in the selection and purchase of fuel are discussed in this section. Most of the data are concerned with solid fuel. Data are included on the cost of coal and electricity in various industries.

Section 5. Preparation of Coal for Utilization. In this section one finds data on chemical treatment of coal and coke, on dewatering and drying of coal, and on crushing and pulverizing of coal.

Section 6. Fuel Handling Methods. This section contains data on handling and storing of solid, liquid and gaseous fuels including information on hazards.

Section 7. The Transfer and Generation of Heat. This section contains information needed for furnace, boiler and steam generator design. Data on methods of firing solid and liquid fuels are also included. One chapter entitled "Some Specific Non-Steam-Making Uses of Fuel" contains information on the sintering of ores, on gas turbines, on dual-fuel internal-combustion engines, on anthracite as a metallurgical fuel and as a filter medium and on other miscellaneous applications. A final chapter is devoted to boiler measurements, temperature measurements and flue-gas analysis.

Section 8. General. This covers boiler measurements and test methods.

From the title one might expect to find in this book more information on fuels for internal combustion engines. There is a tremendous amount of fundamental information on fuels for engines, developed by organizations such as the American Petroleum Institute, that might be added to this handbook to increase its usefulness. It appears that with the increased interest in recent years in fuels for automotive and aircraft power plants and with the increased effort being made to understand the combustion or oxidation processes, more information along this line could be collected into a handbook. If the editors feel that the material should be restricted to combustion engineering in its usual sense then the book should have a title to correspond to this limited field. It is suggested that the present handbook might be the first volume of a series on *Fuels and Combustion* and that the information referred to above might form a second volume of the handbook to be subtitled *Fuels and Equipment for Direct Generation of Power*.

It is believed that the handbook is a very valuable and useful collection of information for those working in the combustion engineering field.

W. E. SCOTT
L. C. CONANT, JR.

QUANTUM THEORY, by David Bohm. 646 pages, diagrams, 16 × 24 cm. New York, Prentice-Hall, Inc., 1951. Price, $7.50.

Many of the books which have been written on the quantum theory have emphasized the mathematical aspects of the subject to such an extent that the reader may fail to visualize the concepts on which this theory is based and to fully understand its importance in explaining phenomena which cannot be explained by classical mechanics.

In this book the author has succeeded in treating the quantum theory in such a way that its physical significance is clearly shown, while at the same time he has made liberal use of mathematics where necessary to state the ideas involved with the necessary degree of precision and exactness.

The book consists of six parts containing a total of twenty-three chapters. In the first part the early quantum theory and the developments which led from this theory to modern quantum mechanics are discussed. The material here is descriptive in nature, principal emphasis being placed on the physical meaning of the topics which are described. Among these topics are the following: the origin of the quantum theory, wave packets and de Broglie waves, the uncertainty principle and the wave *vs.* particle properties of matter.

The mathematical formulation of the quantum theory is treated in part two. Much of the space here is devoted to a mathematical discussion of Schrödinger's equation and related topics. Part three describes the application of these mathematical expressions to specific systems such as the harmonic oscillator and the hydrogen atom. This part also includes a chapter devoted to the matrix formulation of the quantum theory.

The remainder of the book deals in more detail with certain selected topics. Discussed here are: methods for the approximate solution of Schrödinger's equation, the theory of scattering, and the quantum theory of the process of measurement. In this last named section dealing with the process of measurement the author gives the reader considerable insight into the nature of the quantum theory, for here he emphasizes the role of probabilities in this theory which is not of such great importance in classical mechanics.

This book will probably be well received as a text for use in quantum mechanics courses either at the graduate or advanced undergraduate level, since it will give the student a good understanding of the physical significance of the quantum theory before exposing him to the more complete but more abstract, mathematical treatment. The author has included a number of problems in the book which will enhance its value as a text. These problems instead of being placed in groups at the ends of the chapters are distributed throughout the text so that they appear near the material with which they deal. In addition to being useful as a text this book will also be found to be of interest and value to the practicing physicist.

M. D. EARLE

METAL PROCESSING, by Orlan William Boston. Second edition, 763 pages, illustrations, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1951. Price, $7.50.

Written by a man who has been Chairman of the Department of Metal Processing at the University of Michigan for thirty years, *Metal Processing* is concerned with the various stages in the manufacture of a product. Following the introduction wherein such steps involved in readying a product for manufacture as design, selection of material, method of fabrication, and coordination of design within a plant are presented, Professor Boston launches into an unusually thorough description of machine tools, their accessories and their uses. Lathes, shapers, planers, milling machines, sawing machines, screw machines, presses and punches, and all their accessory equipment, their uses and applications, are explained. Such machine operations as drilling, boring, reaming, threading, sawing and broaching; the required tools, jigs and fixtures; and the advantages of each are discussed. Grinding, polishing, buffing, honing and lapping are defined together with the various abrasive wheels, their manufacture,

grading, and care. Other chapters concern cutting fluids, machinability and single-point tools, gears and their manufacture including tooth forms, formulas for teeth and general use, measuring and gaging, and drives for machine tools. A final chapter on cost and accounting practices pertaining to manufacture completes the subject of metal processing.

While the volume is primarily devoted to machine tools and their operations, with a seemingly disproportionate amount to, and coordination of, plant operations, a good picture of the planning required to produce an article is obtained. Beyond saying a designer should consult the metallurgist and purchasing agent before proceeding too far in a design in order to learn what is good and what is available, and the shop to learn what can be made, it must be admitted there's not much more to be said about coordinated design. So it is natural that most of the book is concerned with machine tools.

Questions and references at the end of each chapter help the student to retain what he has read. The many excellent pictures of machine tools, their accessories and their operations help immeasurably to understand the text.

E. W. HAMMER, JR.

TRANSIENT ANALYSIS IN ELECTRICAL ENGINEERING, by Sylvan Fich. 306 pages, diagrams, 15 × 22 cm. New York, Prentice-Hall, Inc., 1951. Price, $5.50.

Many modern applications of electrical engineering require a knowledge of transient analysis, yet there are but few text books which give a good foundation based upon both classical theory and operational methods. The engineer should recognize and know when each of these approaches yields the simplest and quickest solution to his particular problem; an understanding of both approaches is therefore most valuable.

Armed with a background of calculus, college physics, and steady state electric current theory, the reader can simultaneously study alternating current electric circuit theory and transients. Designed for a stiff undergraduate course, the text can also be used in a first graduate course where the students have had little previous work in transients.

Differential equations and their classical solutions for single and double energy systems are considered in the opening five chapters. So many of the elementary techniques for solving first and second order differential equations are so clearly presented that the material is most suitable for part of an engineering mathematics course in differential equations.

The operational methods of solution considered in the rest of the book are: the direct Laplace transformation; Heaviside's expansion theorem; the superposition integral; the inverse Laplace integral; and the Fourier transformation. These methods are applied to a wide variety of elementary electrical engineering problems. To assist in the carrying out of these formal processes, several chapters are included on solutions of higher degree algebraic equations and elements of complex variable theory. One familiar with operational methods will recognize the importance of these subjects. No mention is made of the powerful Graffe root squaring method for determining all roots of a high order algebraic equation; this should be introduced in a future edition. Special mention should be made of the chapters devoted to contour integration, where the author has presented clearly and concisely the material necessary for first applications of operational methods.

Engineers who have not recently been exposed to material on transients may do well to examine this book. It should prove extremely helpful.

S. CHARP

THE NATURE OF METALS, by Bruce A. Rogers. 248 pages, illustrations, 13 × 20 cm. Ames, Iowa, American Society for Metals, and The Iowa State College Press, 1951. Price, $3.00.

The structure and behavior of metals and alloys are described in this small book. It deals principally with the changes which take place as a result of heat treatment and mechanical deformation. The book is not intended for professional metallurgists, but rather for those who for intellectual or practical reasons wish to increase their knowledge of the science of metals.

The book contains twelve chapters, the first of these being a brief discussion of the metallic elements and methods used in the observation of their structure. Chapter two describes the various ways in which atoms arrange themselves in metallic material.

The third and fourth chapters deal with the properties of non-ferrous alloys. The factors

which influence crystal growth and the effects of atomic migration are discussed in the next three chapters. The composition of steels and the methods by which certain desired properties are obtained are discussed in chapters eight and nine. The remainder of the book treats the phenomena of deformation, recrystallization, oxidation and corrosion.

This book is written in such a way that it can be readily understood by those with little previous knowledge of metallurgy. The numerous illustrations and photomicrographs aid greatly in the presentation of the material discussed in the text. There is an appendix containing a description of crystallographic terms. The book also contains a glossary of scientific terms, a bibliography and a list of questions arranged to correspond to the various chapters.

This volume, although non-technical in nature, contains much useful information and should be of value to persons in fields other than metallurgy who wish to learn more of this interesting subject.

M. D. EARLE

EXPERIMENTAL SPECTROSCOPY, by Ralph A. Sawyer. Second edition, 358 pages, drawings and photographs, 16 × 24 cm. New York, Prentice-Hall, Inc., 1951. Price, $5.00.

This book serves as a general introduction to the subject of spectroscopy. It was first published in 1944, and the principal additions to the second edition consist of recent periodical references and descriptions of certain newly developed instruments. The volume should be generally useful to students in learning experimental methods employed in spectroscopy and to scientific personnel whose duties require some general knowledge of this subject. It is not, however, sufficiently detailed to make it of much value to an experienced worker in this field unless the references are consulted.

The book deals mainly with instrumentation and not with the theory of atomic excitation or the mechanism of spectral radiation. The author discusses light sources, the optics of prisms and gratings, quantitative photographic processes, microphotometry, infrared and vacuum ultraviolet spectroscopy and techniques of spectrochemical analysis. Excellent descriptions of the working principles of all practical spectrographic instruments are given.

The only adverse criticism might be that the chapter dealing with light sources is extremely brief. This criticism is made because present investigations tend to indicate that many of the weaknesses of spectrographic methods lie in the light sources, and without careful consideration of this subject many uncertainties are likely to arise. The treatment of electric sparks and arcs is rather weak and indicates the author's unfamiliarity with electrical terms. On the other hand, the sections dealing with the optics of gratings attest the author's competence in this field.

Spectrochemical analysis is becoming increasingly important for control purposes in heavy industries such as high grade steel making. Owing to the rapid progress being made in this field it can be predicted that this portion of the book will within the next few years require extensive revision and expansion.

C. W. HARGENS

ENGINEERING THERMODYNAMICS, by Herman J. Stoever. 458 pages, illustrations, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1951. Price, $5.75.

As the name implies, *Engineering Thermodynamics* concerns the branch of thermodynamics of particular interest to the engineer, that is, only mechanical work, not electrical or magnetic, and only substances that remain chemically unchanged. By concentrating on the fundamentals of thermodynamics and carefully enunciating each principle by word descriptions and illustrative problems, Professor Stoever of Iowa State College has prepared a sound text for undergraduate instruction. Having taught for some fifteen years, he knows student difficulties and how to present his subject in order to be most easily understood.

The book is arranged in three sections. Part I, the first law of thermodynamics, is concerned with such basic properties of substances as pressure, volume, temperature; mechanical work and heat; internal energy and enthalpy; and the analysis of simple processes. Part II, the second law of thermodynamics, is concerned with power cycles and refrigeration cycles, the thermodynamic scale of temperature and entropy. Part III, applications, is concerned with practical industrial problems involving heat and work. In Parts I and II, from theoretical principles Professor Stoever developed methods of calculating work done by a system and heat

added to a system. Applying these methods, he illustrates in Part III the design of such various industrial equipment as steam power plants and internal-combustion engines, refrigeration and air conditioning systems, nozzles and turbines, and such flow measuring devices as venturi meters, flow nozzles, orifices, and pitot tubes.

Due to the intangible nature of its subject, thermodynamics is not an easy field to master. A review of the book indicates that the author is obviously aware of this fact and that he has taken great care to prepare a treatise that is as comprehensible as possible. Professor Stoever has accomplished this task largely by including more than 500 problems of varying degree of difficulty, and by frequent reiteration of salient principles.

E. W. HAMMER, JR.

CLIMATE IN EVERY DAY LIFE, by C. E. P. Brooks. 314 pages, diagrams, 14 × 22 cm. New York, Philosophical Library, 1951. Price, $4.75.

The author, in the introduction to this book states that its purpose is "to provide in a small compass answers to the questions which are most often asked about climate by anyone choosing a site, planning a house, factory or new town, starting up or expanding a business, buying an outfit for a journey overseas, or engaged in any other activity in which the prevailing weather conditions are an important factor." For a book of this length, he does quite well in accomplishing this ambitious objective.

The book is divided into three parts. Part one is entitled "Living With The Climate." In this section climatic conditions in various parts of the world are described. Considerable emphasis is placed on the effects which climate has on industry, health, and general living conditions.

The title of the second part is "Climate as an Enemy." Here the author discusses the distribution and effects of atmospheric phenomena such as floods, hail, ice storms, lightning, hurricanes and tornadoes. There is also a discussion of the deterioration of materials caused by excessive sunlight, temperature, and humidity. One of the chapters of part two is devoted to a discussion of atmospheric pollution.

Part three deals with the control of climate. Some of the topics treated here are: heating, air conditioning, lighting, and man's efforts to alter the weather.

The book contains numerous charts, graphs, and maps which aid greatly in the presentation of the material of the text. Near the end of the book there is a thirteen page table which contains data on the climate in many places throughout the world.

This book will probably serve a useful purpose since it brings together in a single volume much information on the climate in different parts of the world and the effect of climate on industry, travel, and modes of living. The book will be of interest to those persons engaged in activities in which climate and weather are important factors.

M. D. EARLE

RADIO AND TELEVISION RECEIVER CIRCUITRY AND OPERATION, by Alfred Ghirardi and J. Richard Johnson. 669 pages, illustrations, 16 × 24 cm. New York, Rinehart Books, Inc., 1951. Price, $6.00.

This is the first book in the new Ghirardi library for radio service technicians. The next to appear will cover troubleshooting, repair and installation in one volume and test instruments in a second volume. The present book presents first a description of the principles of operation and explanations of the AM, FM, and TV forms of transmission. Most of the book describes, with simplified illustrations, the latest developments in receiver circuits, antennas, transmission lines, electron tubes, and loudspeakers. The disc and magnetic types of home recorders, phonograph pickups, record players, and automatic record changers are also discussed.

This kind of book fills a gap, for technicians and students, between the physics of radio and television on the one hand and such purely practical matters as troubleshooting and repair. It is to be commended for providing the casual reader with clarity of description and the serious reader with review questions and a glossary of recent definitions accepted by the communications industry.

WALTER W. FELTON

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

Dr. Ellice McDonald, Director

***Abstract of* Incorporation of S^{35} from DL-Cystine into Glutathione and Protein in the Rat.**—E. I. ANDERSON AND W. A. MOSHER (*J. Biol. Chem.*, **188**, 717 (1951)). S^{35}-labeled DL-cystine was used to study the metabolism of GSH and tissue protein sulfur in rats. The cystine sulfur was found to be incorporated much more rapidly in GSH than in proteins.

The activity of GSH from intestinal mucosa was comparable to that from liver, and it is suggested that the intestinal mucosa may also be a site of GSH synthesis.

The pattern of cystine sulfur uptake by proteins was similar to that reported for methionine sulfur. The degree of S^{35} incorporation from cystine, however, was considerably less than that reported for methionine.

***Abstract of* Radiation Effects on Liver Glycogen in the Rat.**—M. H. ROSS AND J. O. ELY (*J. Cellular Comp. Physiol.*, **37**, 163 (1951)). Since irradiation had been shown to result in a decrease in the food intake of rats together with an impairment of gastric digestion, it was expected that the amount of hepatic glycogen would decrease after radiation. The amount of glycogen deposited in the cells of the liver, however, was found to increase when fasted rats were irradiated with neutron or x-radiation.

The increase in the amount of hepatic glycogen was not a direct effect of irradiation of the liver or of the adrenals, for it occurred even when these and other portions of the rat body were protected from x-radiation by lead shielding.

CURRENT TOPICS

New Transformers Save Critical Materials.—New transformers, which utilize the most modern advances in insulating materials to save 25 per cent of the copper and silicon steel normally required, and which provide improved efficiency and reduced size and weight, have been developed as a result of a long-term joint research program by engineers of Philco Corporation and Chicago Transformer Corporation, it was announced recently by Leslie J. Woods, vice president-director of engineering and research of Philco, and Donald Schwennesen, Chief engineer of Chicago Transformer.

"This basic advance in transformer design will be widely used in television, radio and electronic equipment and in other fields which require electromagnetic components," Mr. Woods pointed out. "The important advantages, immediately, are the large savings in such critical materials as copper and silicon steel, the improvement in efficiency, and the reduction in size and weight. In the relatively near future we anticipate savings in the cost of various types of transformers and other electromagnetic components used in large quantities throughout the electrical industry for household, industrial and military applications.

"This important new development, which will have widespread applications, is the result of a long-range planned research program accelerated by the necessity for conserving scarce materials. Thus a basic forward step in transformer efficiency has been achieved, and the new designs are certain to replace former methods," Mr. Woods declared.

A full year of research and testing by engineers of Philco and Chicago Transformer went into the selection and evaluation of the materials used in these new transformer designs in order to prove the fundamental soundness required for long operating life. These designs are based on the use of high temperature nylon insulation for the magnetic wire instead of the conventional enamel, and an asbestos type of material for coil insulation instead of the conventional organic and paper insulation. These new materials permit operating the coils at temperatures 25° C. higher than has been permitted by the limits for conventional Class "A" materials.

The extensive data secured from these tests have been submitted to the Underwriters Laboratories for their examination and approval. The Laboratories have agreed to increase the maximum temperature limitations by 25° C. from the 105° C. (hot spot), which is the limit for Class "A" insulation, to 130° C. (hot spot) where the new Philco materials and designs are used in equipment submitted for approval and listing. Since Underwriters Laboratories' approval is required by leading manufacturers of the television, radio and home appliance industries, the sanction of these materials and temperatures is necessary for widespread application in the near future.

Participating in the tests in this transformer development program with Philco and Chicago Transformer were engineers of Essex Wire Company, manufacturers of the magnet wire, and E. I. du Pont de Nemours & Company, manufacturers of nylon for the high temperature wire coating.

New Projection Paper.—A new, faster, projection paper, designed especially for the professional photographer, is being introduced by the Du Pont Company. Called High Speed "Varigam" variable contrast photographic paper, the new product has all the control advantages of the regular "Varigam" and is two to three times faster.

Used with filters—the same ones that are used with "Varigam" papers—its speed is equal to that of "Velour Black" Normal photographic projection paper. Except for the use of filters to control contrast, the new paper is printed and processed in the same manner as conventional enlarging papers.

Having come through a series of extended field evaluation tests with distinction, High Speed "Varigam" promises to simplify printing and storing problems particularly for portrait, press and commercial photographers, while at the same time providing printing contrasts not available in conventional projection papers.

For the press photographer, who must frequently shoot under adverse conditions, the local contrast control offered by the new paper is often the only technique for making a high quality print from unbalanced negatives. One box of High Speed "Varigam" in the darkroom is sufficient for printing negatives that might normally require four or more grades of ordinary paper.

High Speed "Varigam" is at present available in two surfaces: R—white glossy, single weight; and DL—velvet grain natural white luster, double weight. Other surfaces will be added. It comes in all sheet and roll sizes and in 50, 100, 250, and 500 sheet packages.

Master Precision Timekeeper.—A new and extremely precise "master timekeeper"—probably the most precise in existence—has just been placed in operation at the Bell Telephone Laboratories at Murray Hill, New Jersey. It is expected to vary less than one ten-thousandth of a second per day; this corresponds to a precision of one second in 30 years.

The secret of such split-second precision lies in four extremely stable quartz crystals which vibrate constantly at a frequency of 100,000 cycles per second. The vibrations of these crystals control the frequency of a special electric current with a precision of one part in a billion.

The new timekeeper is known technically as the Bell System Primary Standard of Frequency. It is the yardstick for the precise measurement of frequency and time throughout the Bell System.

The apparatus is used by the telephone companies to monitor or regulate equipment for the coaxial cable and radio relay television and telephone networks, as well as overseas, ship-to-shore and mobile radiotelephone service.

"Time-of-day" service in New York City is controlled by the new apparatus, as is the "world's most accurate public clock" in the display window of the American Telephone and Telegraph Company at 195 Broadway, New York.

Radio broadcast network switching clocks are also controlled by this new device. The time-frequency measurement service is provided to the Consolidated Edison Company which uses it for regulating electric light and power services throughout the northeastern United States.

In addition to the practical value of such a precise standard, the new apparatus is important scientifically for it will provide a third, independent

reference for time measurement. Extremely accurate measurements already are made by the U. S. Naval Observatory by astronomical observations, and by the National Bureau of Standards. A third very precise check at Bell Laboratories will be of great aid in explaining any variations between the other two sources.

The entire apparatus contains about 600 electron tubes and has well over 25,000 soldered connections. It represents the culmination of about five years of effort on the part of Bell Laboratories engineers under the direction of J. G. Ferguson, W. J. Means, and E. P. Felch. G. N. Packard is in immediate charge of operation.

To insure continuous operation of the equipment, power is derived from storage batteries ordinarily charged from commercial power sources. A generator driven by a steam turbine is provided for charging the batteries indefinitely if necessary.

The new equipment is housed in air-conditioned rooms where the temperature never varies more than two degrees. The quartz crystals themselves—each about the size of a paper matchbook—are enclosed in containers from which all the air has been pumped out. These in turn are surrounded by thermostatically controlled ovens to maintain the temperature of the quartz crystals constant to within a hundredth of a degree.

The new apparatus replaces a similar device which had been in continuous operation since 1937 at the New York headquarters of the Bell Laboratories. It is expected to be ten times as precise as this older equipment. In addition, it is simpler in operation and in maintenance requirements.

Pioneer work on quartz crystal clocks was done by W. A. Marrison, also of Bell Laboratories, who has achieved international recognition for his contributions to this field.

New Packaging Method for Photographic Sheet Film.—In what is regarded by its film experts as a revolutionary change in packaging methods, Du Pont's photographic sheet film is now being delivered to consumers without the usual black interleaving paper between sheets of film. The new packages are identified by a special label since only a part of the company's present film production has thus far been converted to the new method.

Before being released for general distribution, the new package was tested over a three-year period in Du Pont laboratories and in limited consumer field trials. The results showed that film packaged in the new way is cleaner, that it is quicker and easier to handle, and, most important of all, will stand up better under prolonged storage.

Furthermore, by doing away with the "slip-sheets," the photographer is spared the customary darkroom litter, and his loading time is reduced by as much as 50 per cent. Possible film spoilage or negative defects resulting from paper dust, carbon spots, or moisture absorbed from the interleaving paper are eliminated, and the risk of loading the paper in holders or losing film among the interleaves is avoided.

Although Du Pont still considers this change as experimental, the reception to date has been so favorable that present plans are to produce steadily increasing quantities of the new package during coming months.

Biologic Shock Absorber.—ACTH—the drug from the pituitary gland that doctors are now trying out on human diseases—may be the biologic shock absorber that cushions birds, as well as mammals, against life's hard knocks, according to evidence gained by biologists at the University of Wisconsin and the Wisconsin conservation department.

The workings of ACTH may also help to explain one of the oldest of animal world mysteries—population cycles, the rhythmic ups and downs of wildlife populations so well known to hunters, trappers, and zoologists.

The pituitary gland, located at the base of the brain and, in humans, about the size of a navy bean, regulates body growth, thyroid activity, reproductive functions, and produces the substance known as ACTH which controls the adrenal cortex.

How ACTH influences the ability of the animal body to survive stresses and strains of long duration, such as excessively hard winters, is being studied by UW scientists June Baum, Fred Greeley, Dorothy Koehler, Lester Van Horne, and Prof. Roland K. Meyer, and Wisconsin conservation department researchers Cyril Kabat and Kenneth Flakas.

When times get tough, the pituitary secretes more ACTH, so the scientists believe, which in turn stimulates the adrenal cortex into stepped-up production of cortisone, a substance which seems to help animals speed up certain needed physiological activities, such as turning body protein into energy during periods of food shortage.

"The adrenal cortex seems to be the gland that bestows upon the organism the ability to meet the stresses and strains of extended hard times," the scientists point out.

At present the scientists are trying to verify their hunch that game birds are equipped with the same pituitary-ACTH-cortisone stress meeting mechanism as the mammals.

They have found evidence that pheasants and chickens seem to be able, like mammals, to produce cortisone even under starvation conditions. The birds are also able to maintain high blood sugar levels by utilizing body protein for energy—a cortisone governed function.

Present theory holds that while ACTH may help birds and animals meet one stress or perhaps a number of them, if the stresses and strains become too numerous, the biologic cushion will no longer work. This may help explain why wildlife populations suddenly crash upon reaching a certain level of abundance. Perhaps the population density becomes the critical factor, the scientists say.

It has been known for some time that environmental stress results in lowered breeding rates. This, too, can be explained in terms of the pituitary, which can manufacture only a limited quantity of hormones. When an animal experiences a high demand for ACTH during a hard winter, for example, the capacity to reproduce, which is a pituitary-initiated function, may suffer.

More information on how ACTH works will most likely give game managers some useful hints on how to meet the problems of wild animal survival. It may, in addition, add to medicine's understanding of the effect of stress on humans.

Modern medicine has recently been placing more importance on the effect of prolonged stress upon humans, and many believe that over-production of

ACTH and cortisone may be the cause of some of the so-called "diseases of modern life," such as ulcers, high blood pressure, heart disease, and the other maladies which are the result of living and working under constant tension, the biologists point out.

Industrial X-ray Equipment (*Electrical Review*, Vol. CXLVIII, No. 3835).—The latest industrial X-ray unit to be introduced by Philips Electrical, Ltd., is known as the "Compactix." It is entirely new in conception and the makers claim that it greatly simplifies procedure and leads to a speedier rate of inspection.

The X-ray unit proper is cylindrical and is divided internally by two insulating partitions. The h.v. energizing source comprises two specially designed transformers, each developing 100 kVp to earth. The transformers, together with the X-ray tube, are oil immersed, the tube being housed in the central compartment. The transformers are directly connected to the tube with which they are thus in series, an additional filament heating transformer being provided on the cathode side. The tube, which has a continuous rating of 200 kVp to 10 mA, acts as its own rectifier and there are no valves or h.v. cables.

The X-ray beam emerges from a window in the wall of the container, the position of the focus being the geometric centre of the whole.

The control unit is small and designed to facilitate easy transport while reproducible operating conditions are made possible by means of a mains compensator, and a stepless auto-transformer, working in conjunction with a kilovoltmeter, enables the penetration to be controlled with a high degree of precision. The tube current, which can be varied, is indicated by a milliammeter. Cooling is normally effected from the water main, but a trolley mounted closed circuit system is available for use where the mains water supply cannot be relied upon.

The unit can be mounted on a truck with hydraulically operated raising and lowering gear, permitting a very wide range of vertical adjustment. For use in shipyards and on outdoor structures, the X-ray head is provided with slings so that it can be used independently of any other form of mounting. For such work the cylindrical form of the tube head permits of easy passage through a manhole.

The equipment is completely shockproof and fully protected, while its operation is unaffected by humidity or altitude. It has a radiographic penetration of 3 in. of steel in an economical exposure time, and is constructed to operate from single-phase 220–250 V 50–60 c/s mains.

A "flying printing press" developed under Air Force Aeronautical Chart and Information Service guidance combines a complete offset printing press with all tools, auxiliary equipment, and supplies in an 8000 pound package transportable by Air Force cargo planes. The portable press room is carried in a shipping container made of cabinets and panels which break down to form needed press room facilities; the unit can be unloaded and in operation within two hours. Press capacity is 6500 sheets of $22\frac{1}{2} \times 30$ inch stock per hour. Additional units will be supplied Army and Air Force activities by the builder, Harris-Seybold Company of Dayton, Ohio.

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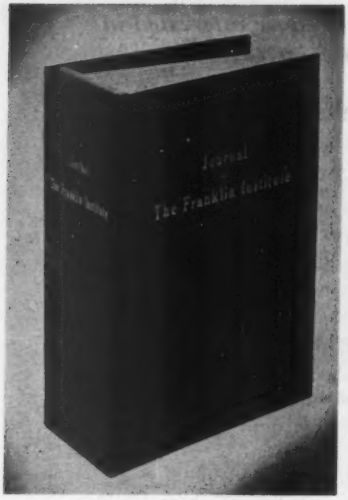

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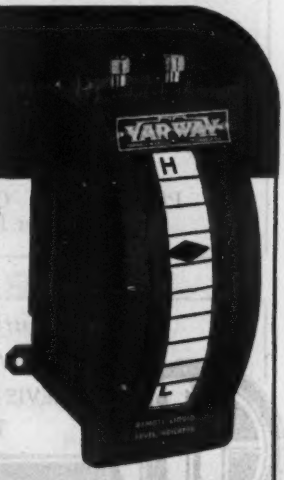

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The Elliott Cresson Medal (1848—Gold Medal).—This medal is awarded for discovery or original research, adding to the sum of human knowledge, irrespective of commercial value; leading and practical utilizations of discovery; and invention, methods or products embodying substantial elements of leadership in their respective classes, or unusual skill or perfection in workmanship.

The Howard N. Potts Medal (1906—Gold Medal).—This medal is awarded for distinguished work in science or the arts; important development of previous basic discoveries; inventions or products of superior excellence or utilizing important principles.

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The Edward Longstreth Medal (1890—Silver Medal).—This medal is awarded for inventions of high order and for particularly meritorious improvements and developments in machines and mechanical processes. In the event of an accumulation of the fund for medals beyond the sum of one hundred dollars, it is competent for the Committee on Science and the Arts to offer from such surplus a money premium for some special work on any mechanical or scientific subject that is considered of sufficient importance.

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The Boyden Premium (1859).—This premium is awarded not oftener than once in five years to any resident of North America who has recently made a notable experimental determination of the speed, in free space, of radiation in any region of the entire spectrum.

The William M. Vermilye Medal (1937—Bronze Medal).—This medal is awarded not oftener than biennially in recognition of outstanding contribution in the field of Industrial Management.

The Certificate of Merit (1882).—A Certificate of Merit is awarded to persons adjudged worthy thereof for meritorious inventions, discoveries or improvements in physical processes or devices.

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(Revised to August, 1951.)

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